Superheavy Element Research at TASCA

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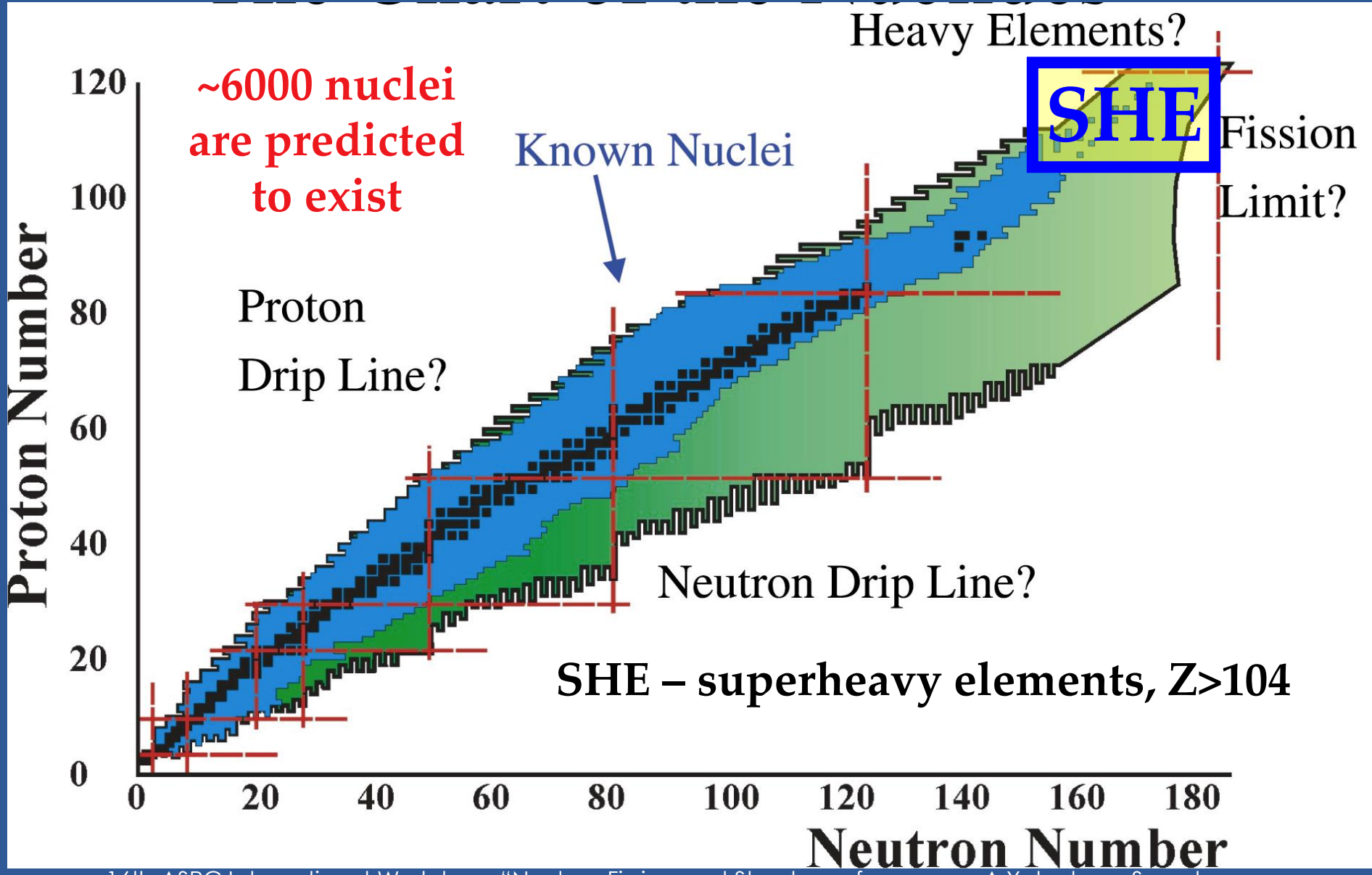
The *TASCA* Collaboration

LBNL/UCB Berkeley (USA)
LLNL Livermore (USA)
Vanderbilt U (USA)
ORNL Oak Ridge (USA)
U Liverpool (UK)
U Surrey (UK)
U Lund (Sweden)
JAEA Tokai (Japan)

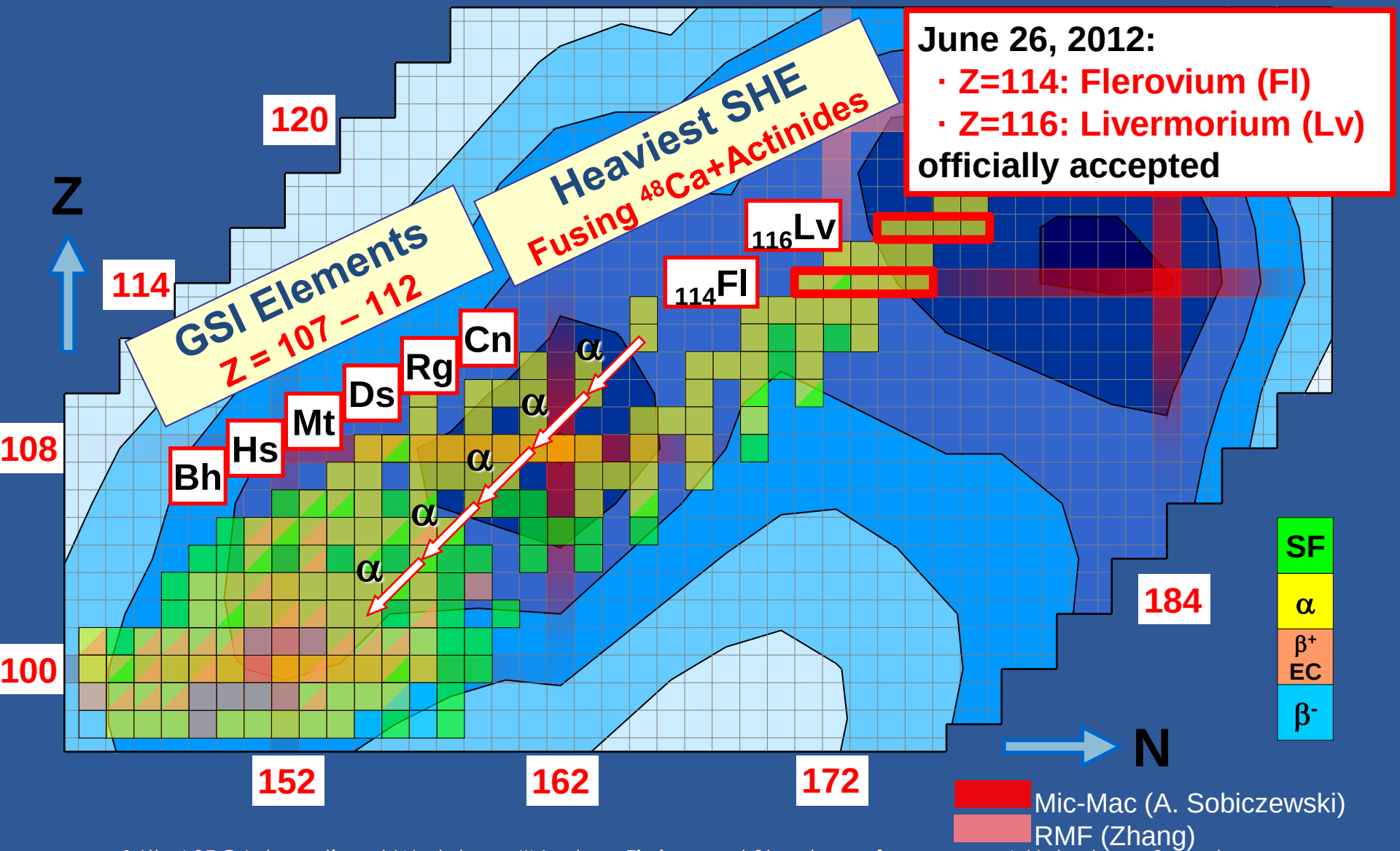
U Jyväskylä (Finland)
U Oslo (Norway)
Chalmers U Gothenburg (Sweden)
PSI Villigen/U Berne (Switzerland)
ITE Warschau (Poland)
SINP Kolkata (India)
IMP Lanzhou (China)
ANU Canberra (Australia)

16 institutions from 11 countries

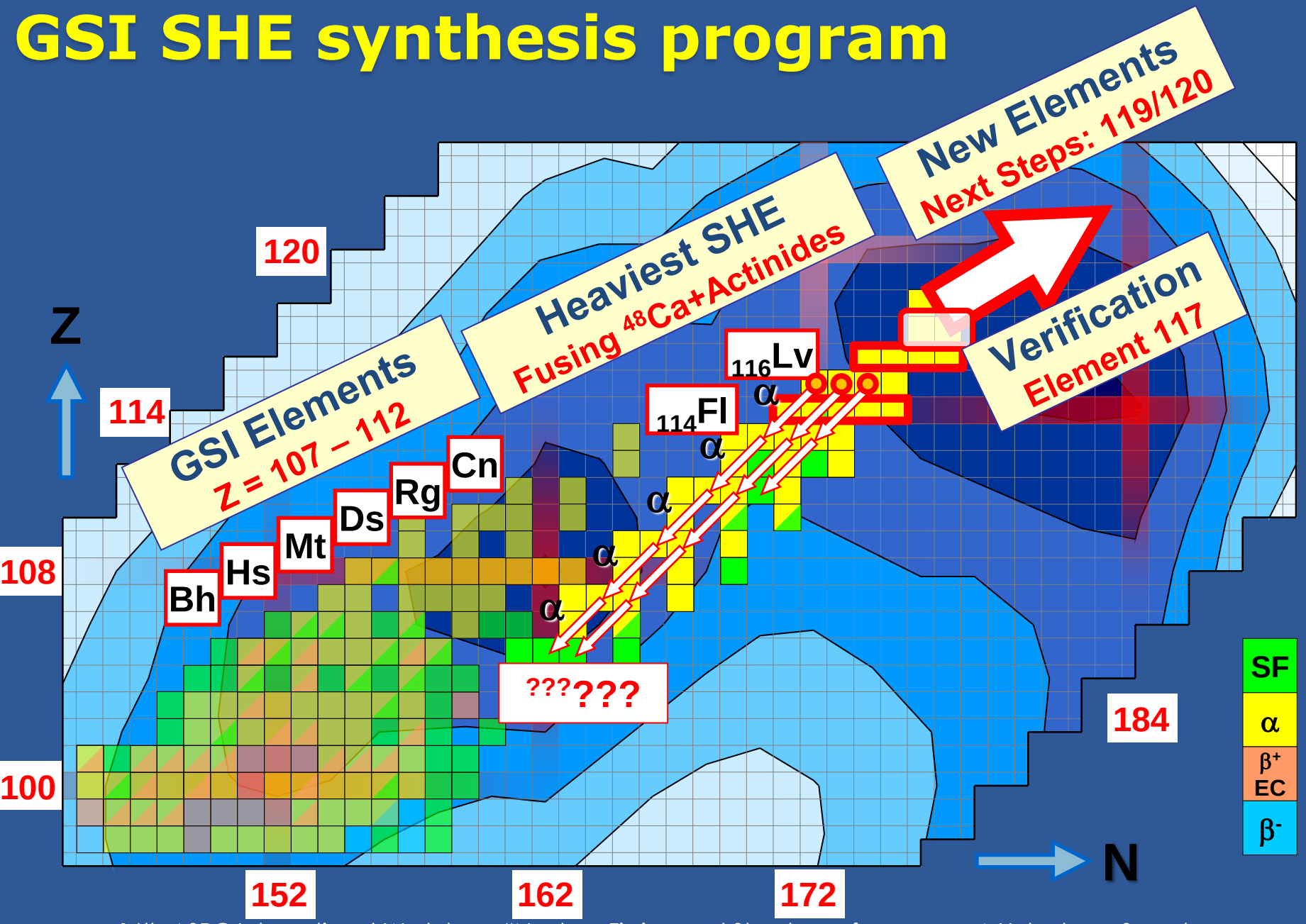
Map of the Nuclear Landscape



Superheavy Elements – Current status

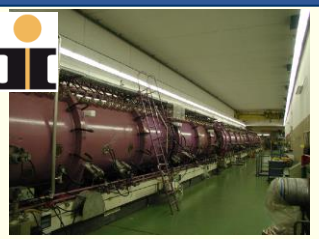


GSI SHE synthesis program



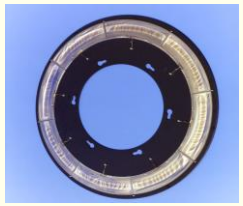
Unique Combination for SHE Studies

Today's talks by F.P. Hessberger und M. Block



ECR(PIG) + UNILAC

Beam

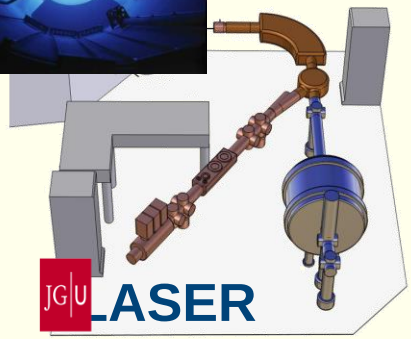


Stable targets

Actinide targets

Radiochem. labs

TRIGA-



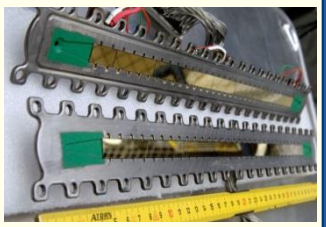
LASER

-TRAP

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

SHIP

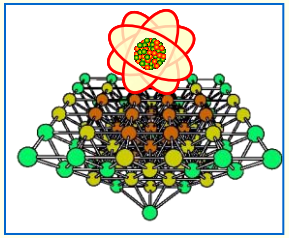
TASCA



Chemistry

SHIPTRAP

TASISpec/Lund



Chemical theory

TransActinide Separator and Chemistry Apparatus - a Separator for Actinide Based Reactions

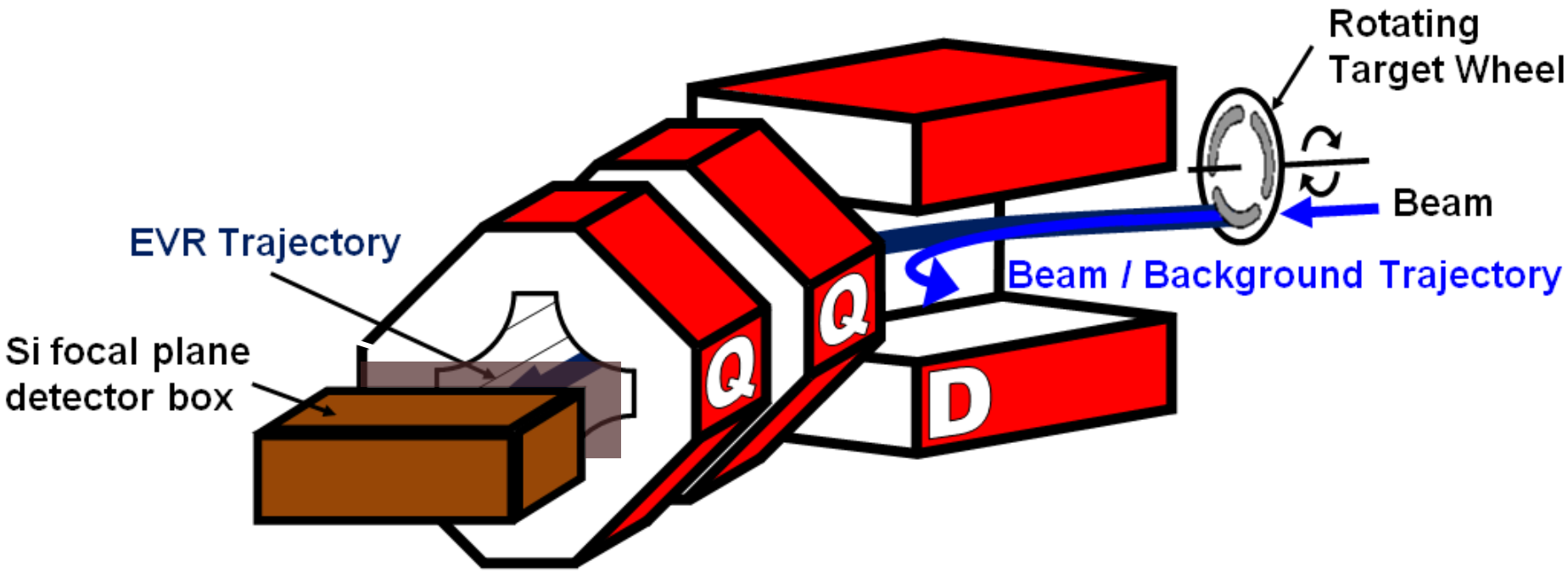
Classical gas-filled

DQ_hQ_v-configuration, length 3.5 m

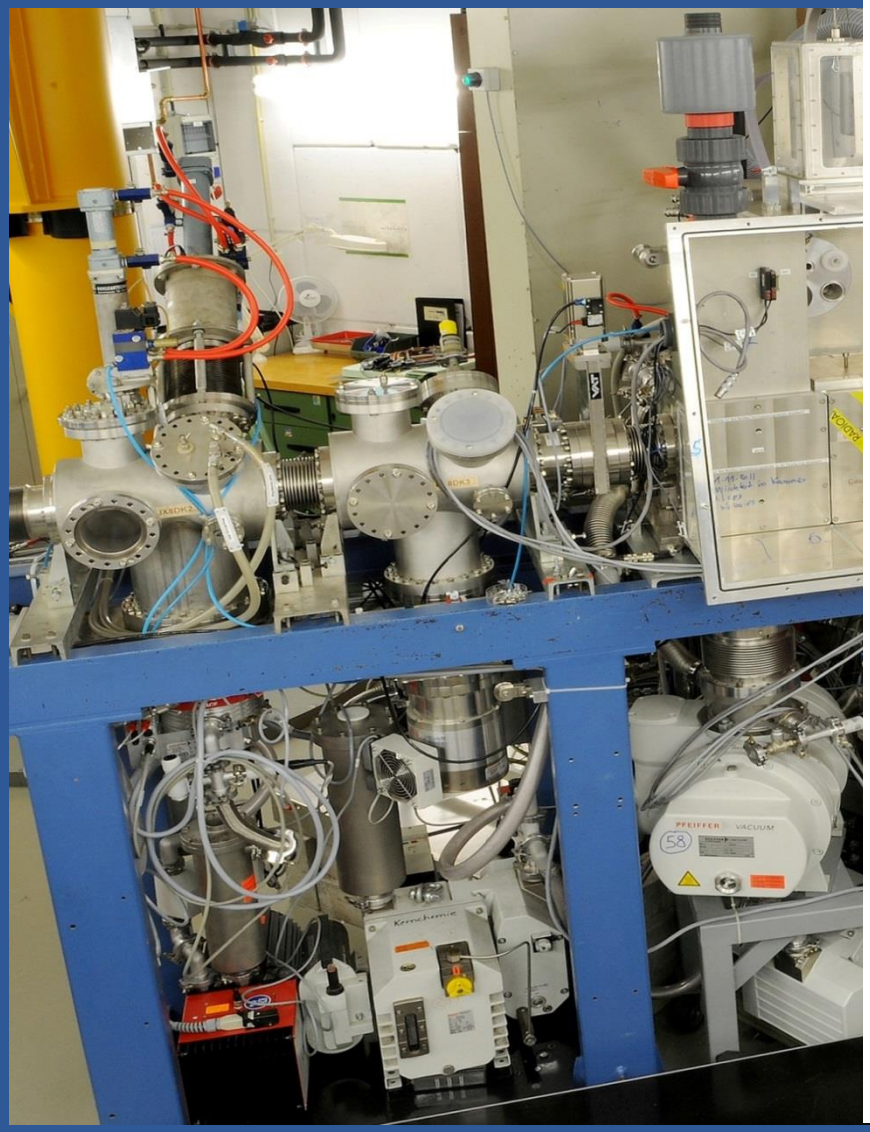
maximized transmission

Calculated efficiency for $^{50}Ti + ^{249}Cf$ - (60±6)%

@ 500 μg/cm^2 target thickness



TASCA



Timeline

2002 goals defined

2003 community formed

2004 decision: gas-filled separator

2005 start building TASCA

2006 first beam in cave

2008 TASCA commissioning completed

2008 First experiments with transactinides

2009 Decay properties and chemistry of Fl (Z=114)

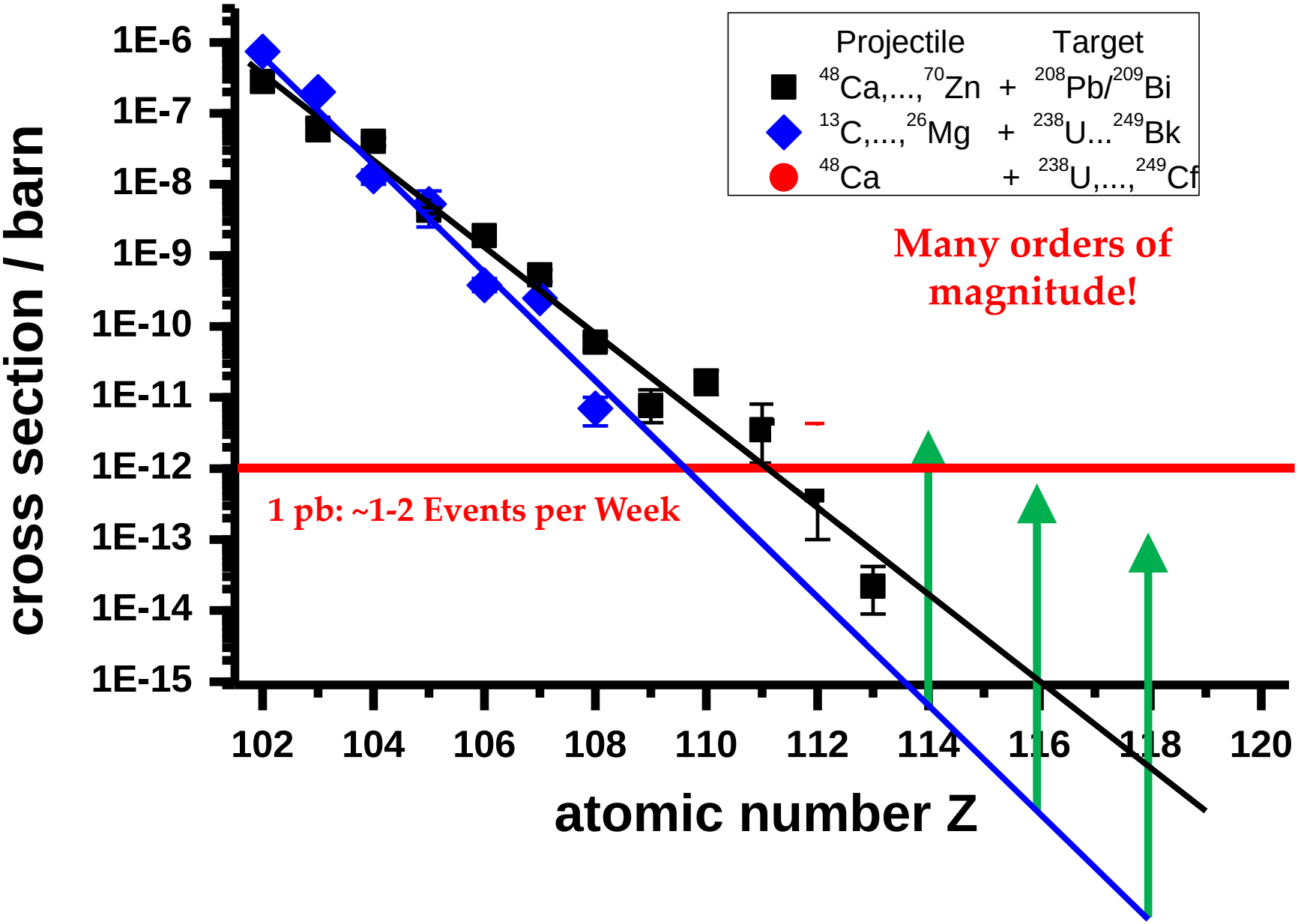
2011 Search for E120 in $^{50}Ti+^{249}Cf$ reaction

2012 Search for E119 in $^{50}Ti+^{249}Bk$ reaction

Synthesis of E117

Spectroscopy of E115

Synthesis of superheavy elements



How to synthesize elements 119 and 120?

Z_{Beam}	Beam	Target	Asymmetry (Fusion prob.)	$E^*@B_{Bass}$
21	^{45}Sc	^{249}Cf		41.7
22	^{50}Ti	^{249}Bk		32.4
26	^{58}Fe	^{244}Pu		33.9
27	^{59}Co	^{237}Np		32.9
28	^{64}Ni	^{238}U		27.3

$^{50}Ti + ^{249}Bk$ and $^{50}Ti + ^{249}Cf$

are most promising reactions for

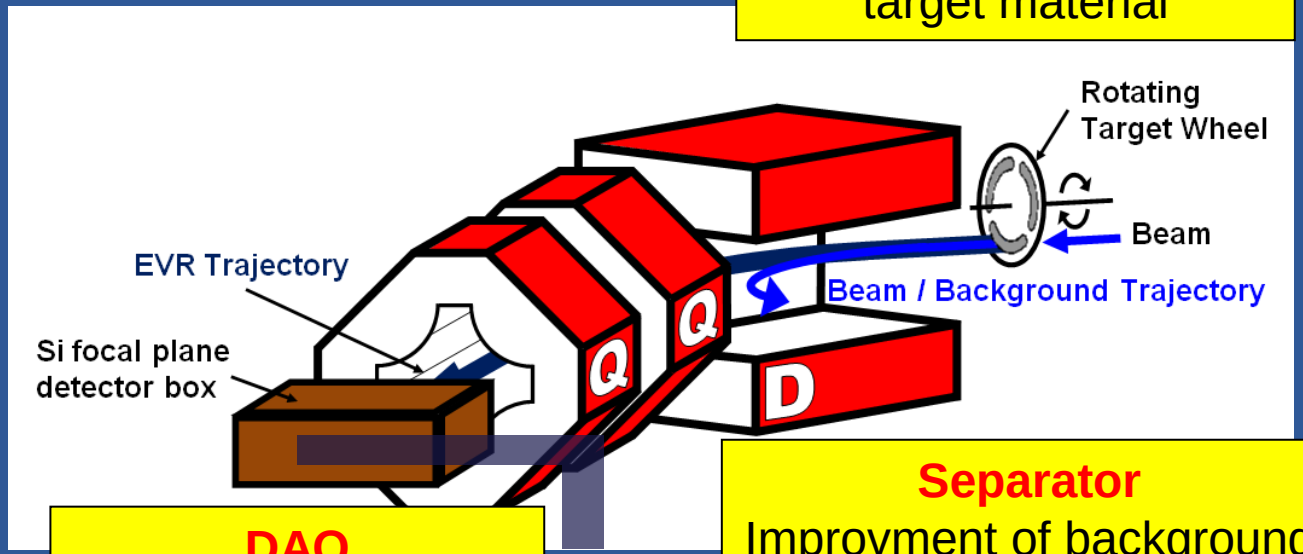
synthesis of elements beyond Z=118:

<u>asymmetric and rather cold</u>

Search for new SHE: Challenges

Target
Target wheel
for high intensity beam

Exotic highly radioactive
target material



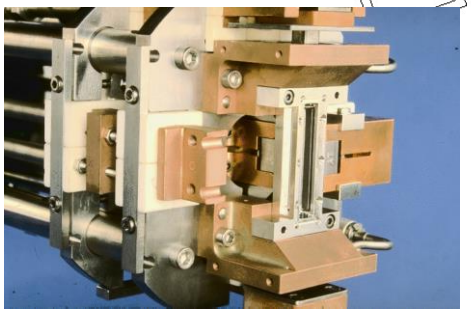
Beam
Reliable
^{50}Ti beam
of high intensity

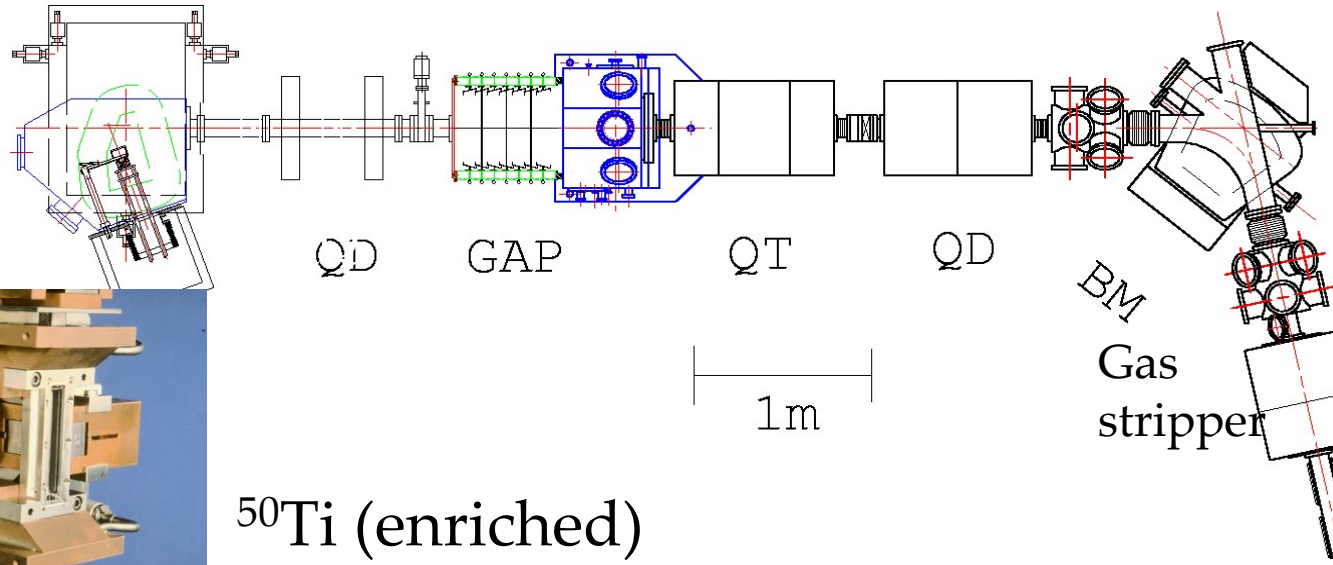
Separator
Improvment of background
suppression

DAQ
Fast "dead-time-free"
digital electronics
for fast decays

Beam

PIG





$^{50}Ti^{2+}$

50 μA

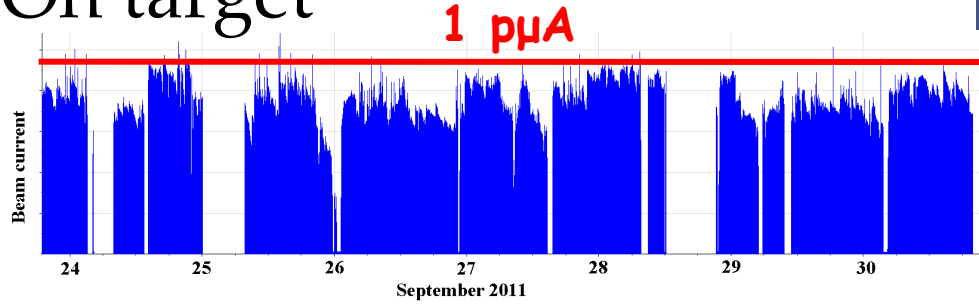
$^{50}Ti^{12+}$

80 μA

to UNILAC

^{50}Ti (enriched)

On target

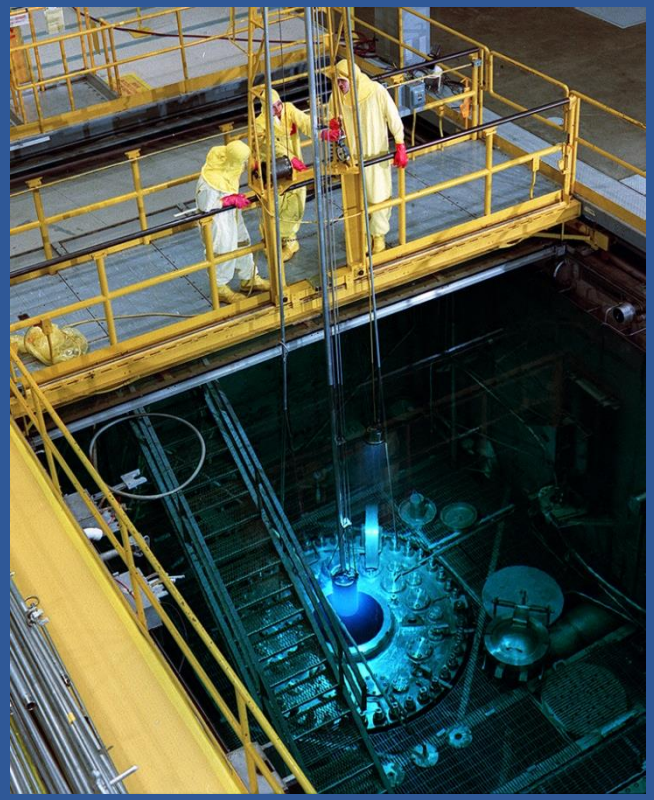


Target: ^{249}Bk production for search for E119

Irradiation of Am/Cm-targets in the HFIR @ ORNL

$\Phi_{thermal}$ at HFIR: 2.5×10^{15} neutrons/cm^2·s

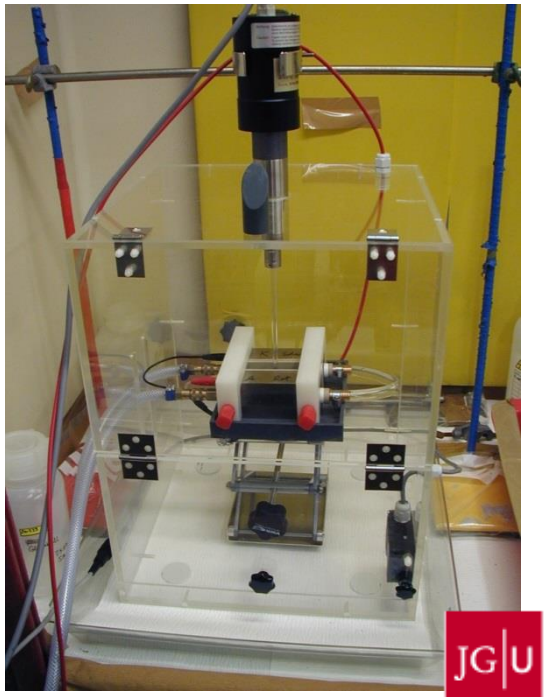
- Targets remain in the reactor for approximately 18 months
- 31 target positions (10–13 targets typically irradiated)
- Produces ~35 mg ^{252}Cf per target (smaller quantities of Bk, Es, Fm)
- Chemical processing of irradiated targets and separation of Bk



OAK RIDGE National Laboratory

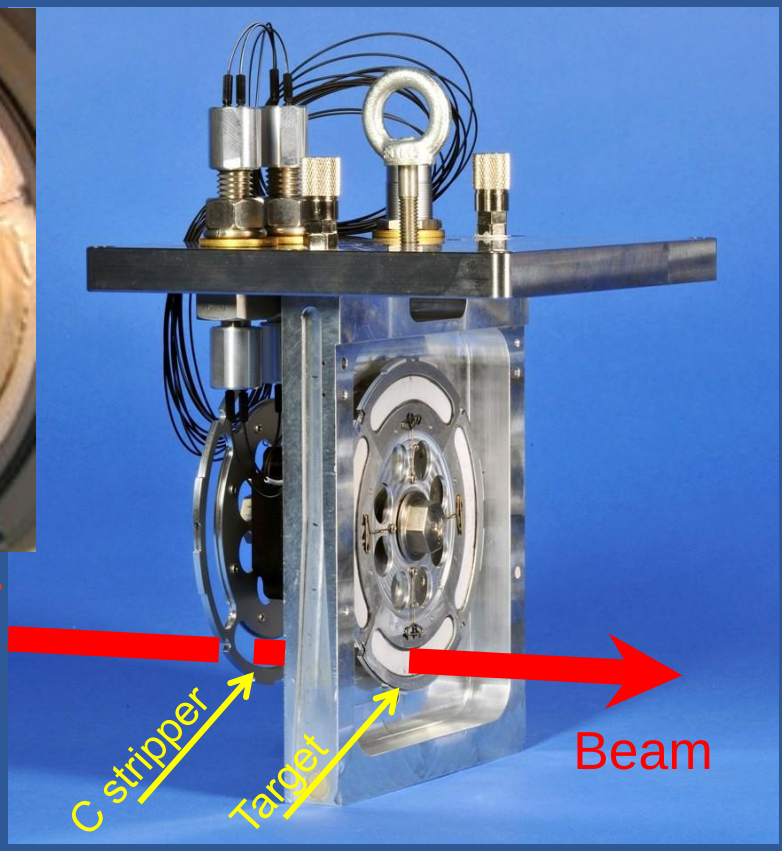
Target

Making actinide targets

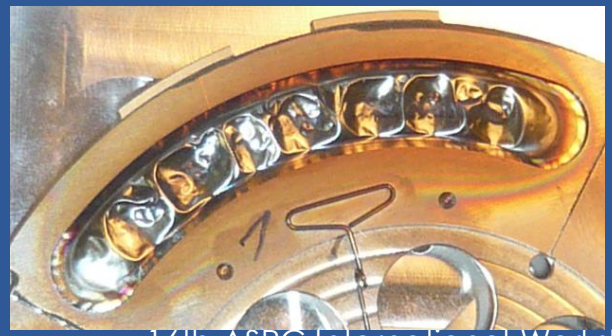


Used for E120 and E119

Ø Beam Spot: 8 mm



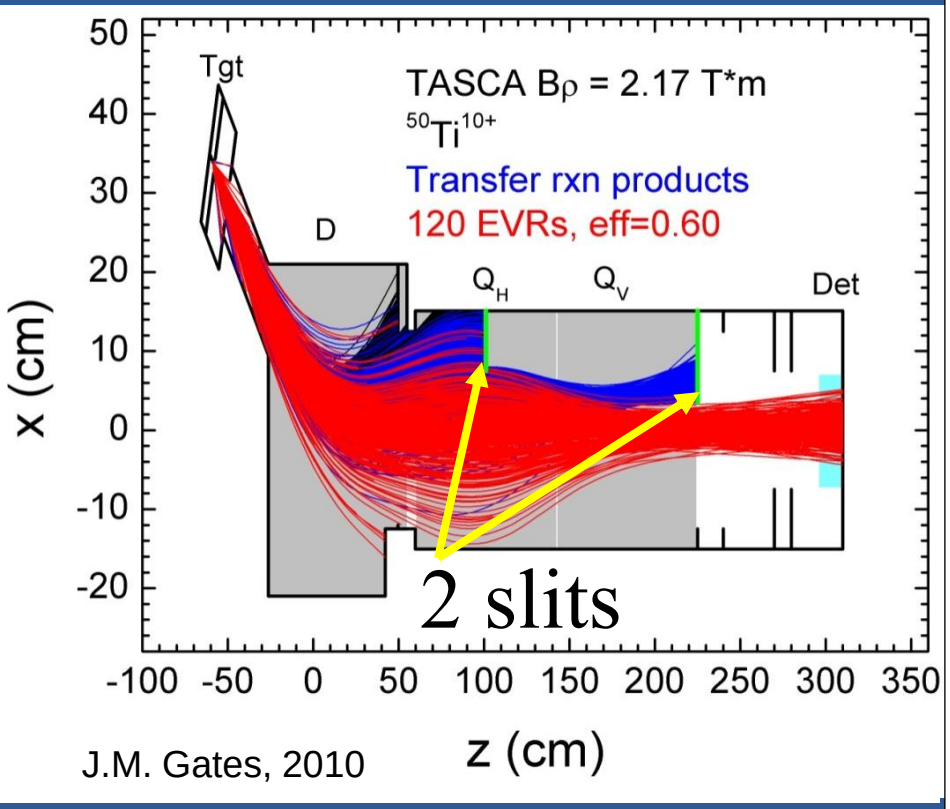
Target tested with ^{40}Ar up to 2.5 particle·µA



No destructive changes after >4·10^{19} ^{50}Ti ions

E. Jäger *et al.*, J. Radioanal. Nucl. Chem.; 2013
J. Runke *et al.* J. Radioanal. Nucl. Chem.; 2013

Background reduction in *TASCA*



Improvement compared to 2009:

Event rate in FPD

@ Bρ=2.28 Tm

2009	**2011**
312 pnA ^{48}Ca	750 pnA ^{50}Ti
438 μg/cm^2 ^{244}Pu	~500 μg/cm^2 ^{249}Cf
Rate: 1230 Hz	**Rate: 300 Hz**
per 100 pnA / 0.5 mg/cm^2	per 100 pnA / 0.5 mg/cm^2
450 Hz	40 Hz

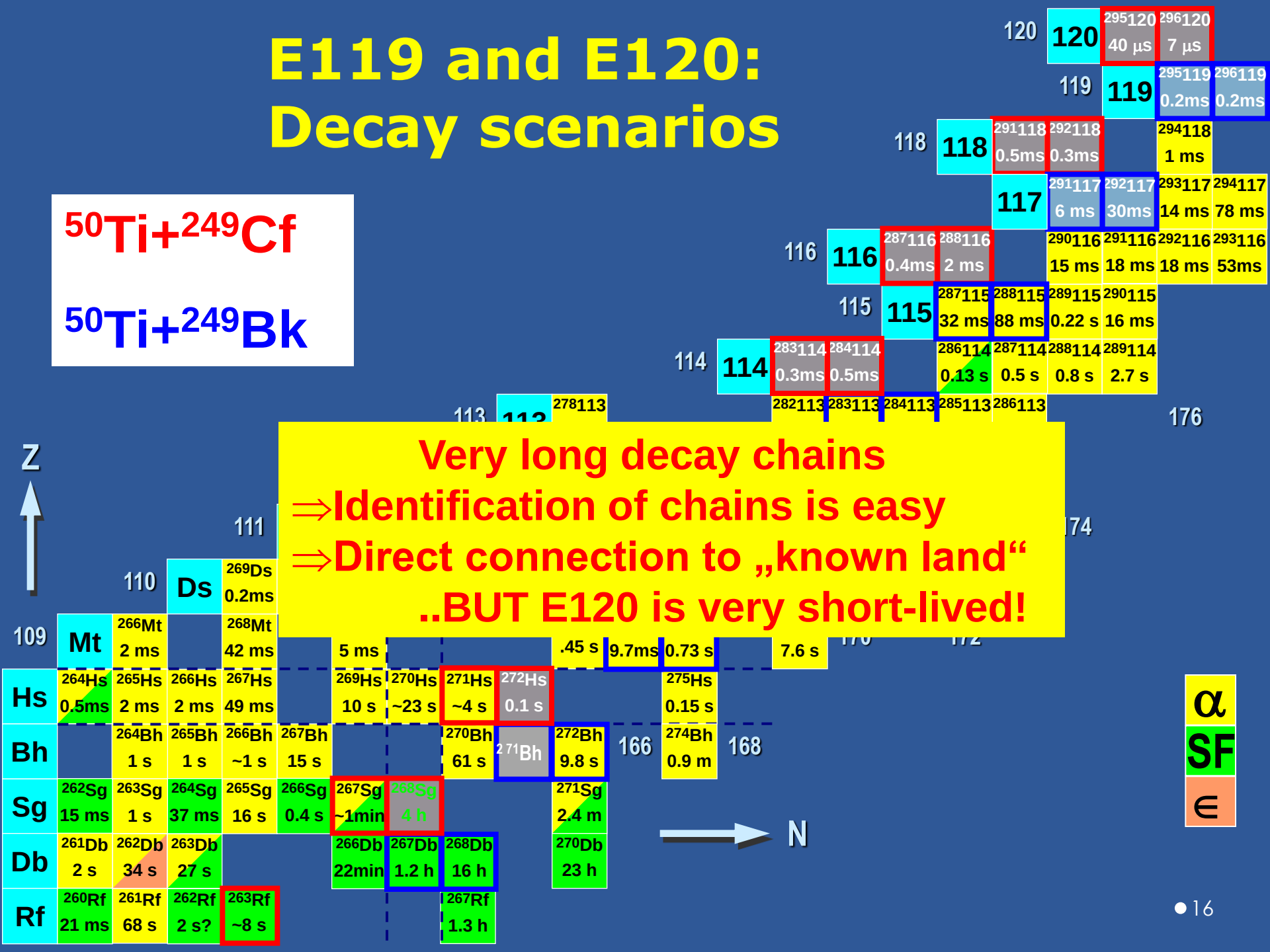
Background reduction by factor ≥10

Efficiency loss for EVRs minimal, as confirmed in ^{48}Ca+^{208}Pb

E119 and E120: Decay scenarios

$^{50}Ti + ^{249}Cf$

$^{50}Ti + ^{249}Bk$



A new Combined ANalog/DIgital (CANDI) DAQ system for μs-isotopes

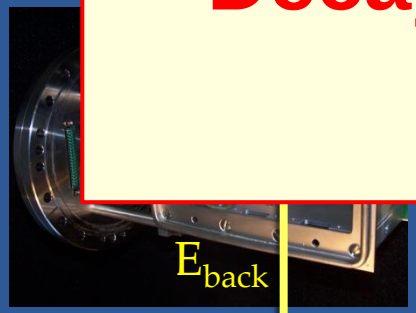
Analog path

Stop detector, p-side: 144 strips

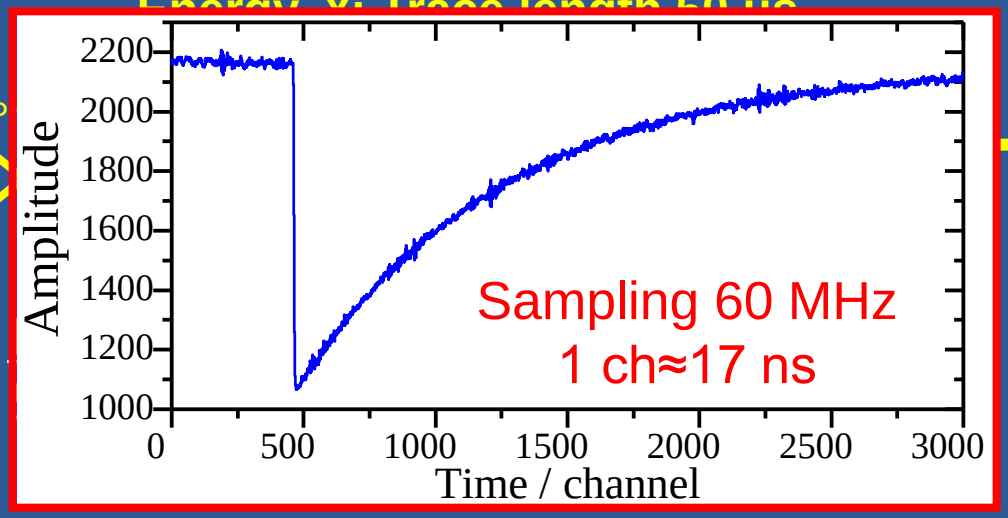
Dead-time free!

Decays with lifetimes down to about

100 ns can be determined



48 strips



Event Builder

Digital signal processing

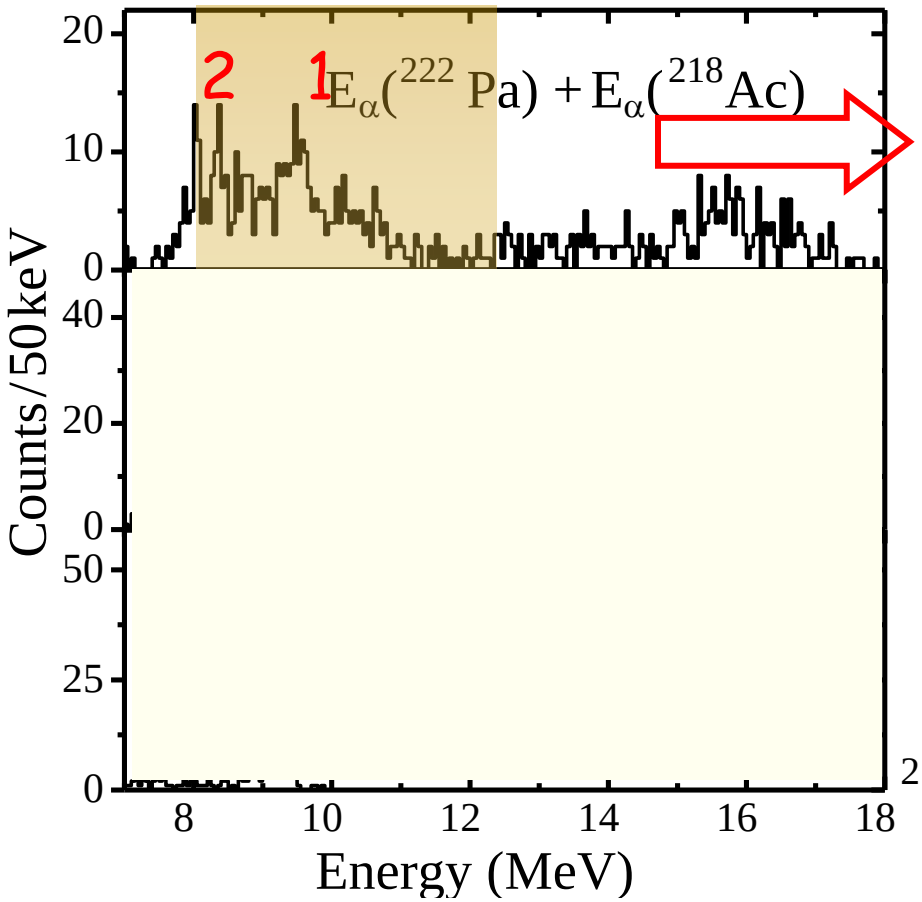
Pile-up

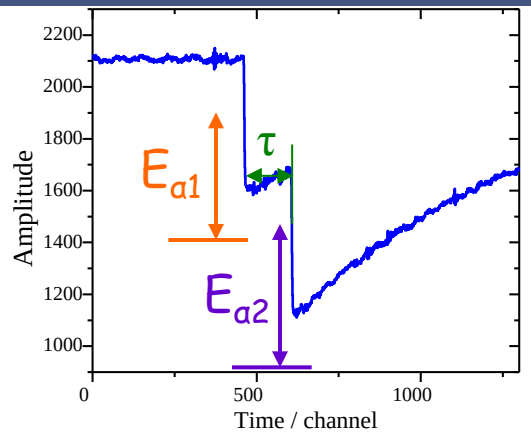
^{222}Pa
8210..;3ms

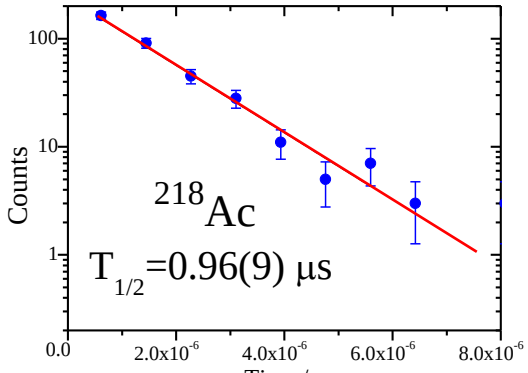
ER: p3n

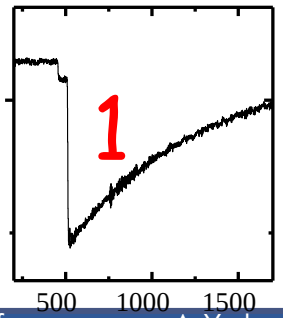
^{218}Ac
9210;1μs

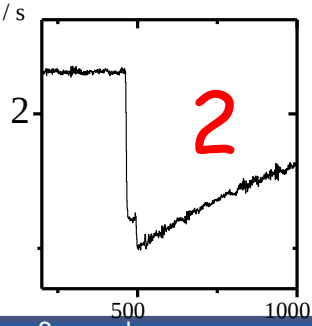
^{214}Fr
8420;4ms





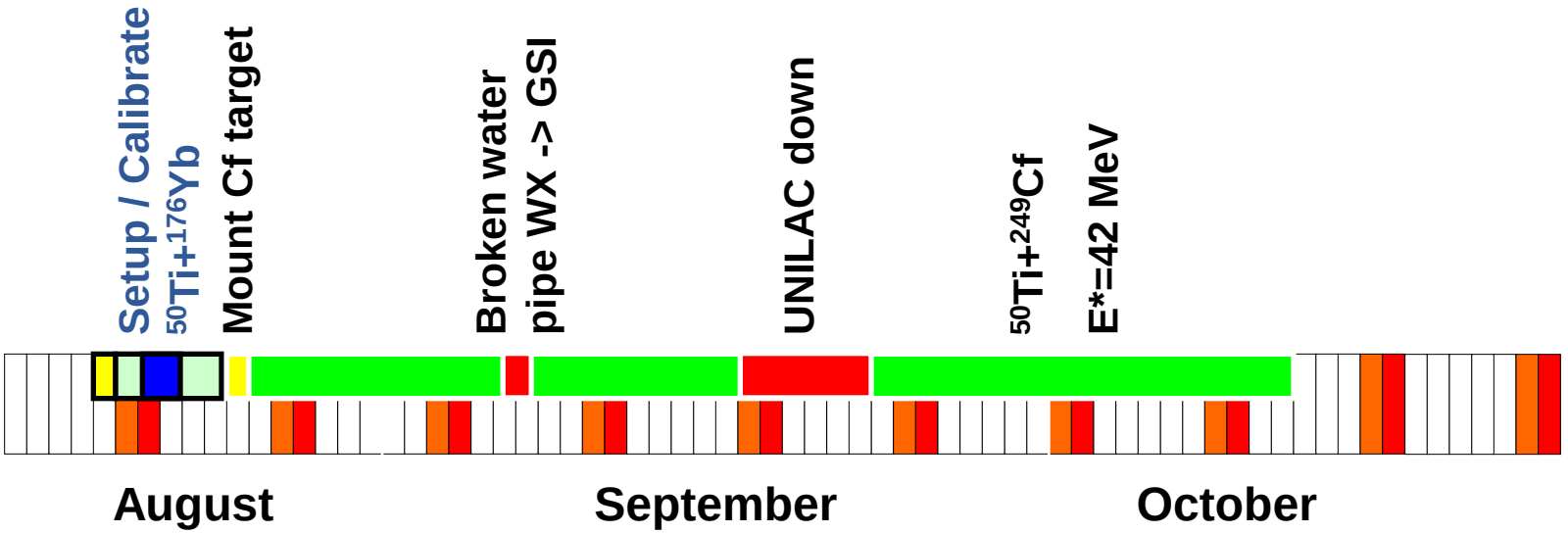






J. Khuyagbaatar et al., GSI Scientific Report 2011, 212 (2012)
to be published

2011: The ^{50}Ti + ^{249}Cf run to search for E120



Setup / Test / Calibrate **7 days**

UNILAC operational for Cf **~39 days**

(Beam on target, data taking **~35 days)**

Beam dose: About $9.22 \cdot 10^{18}$; about 7 TB of data

Cross section limit for the one event observation 200 fb!

2012: Search for element 119

Status of element 119 search:

beam dose: ≈$3.6 \cdot 10^{19}$ particles

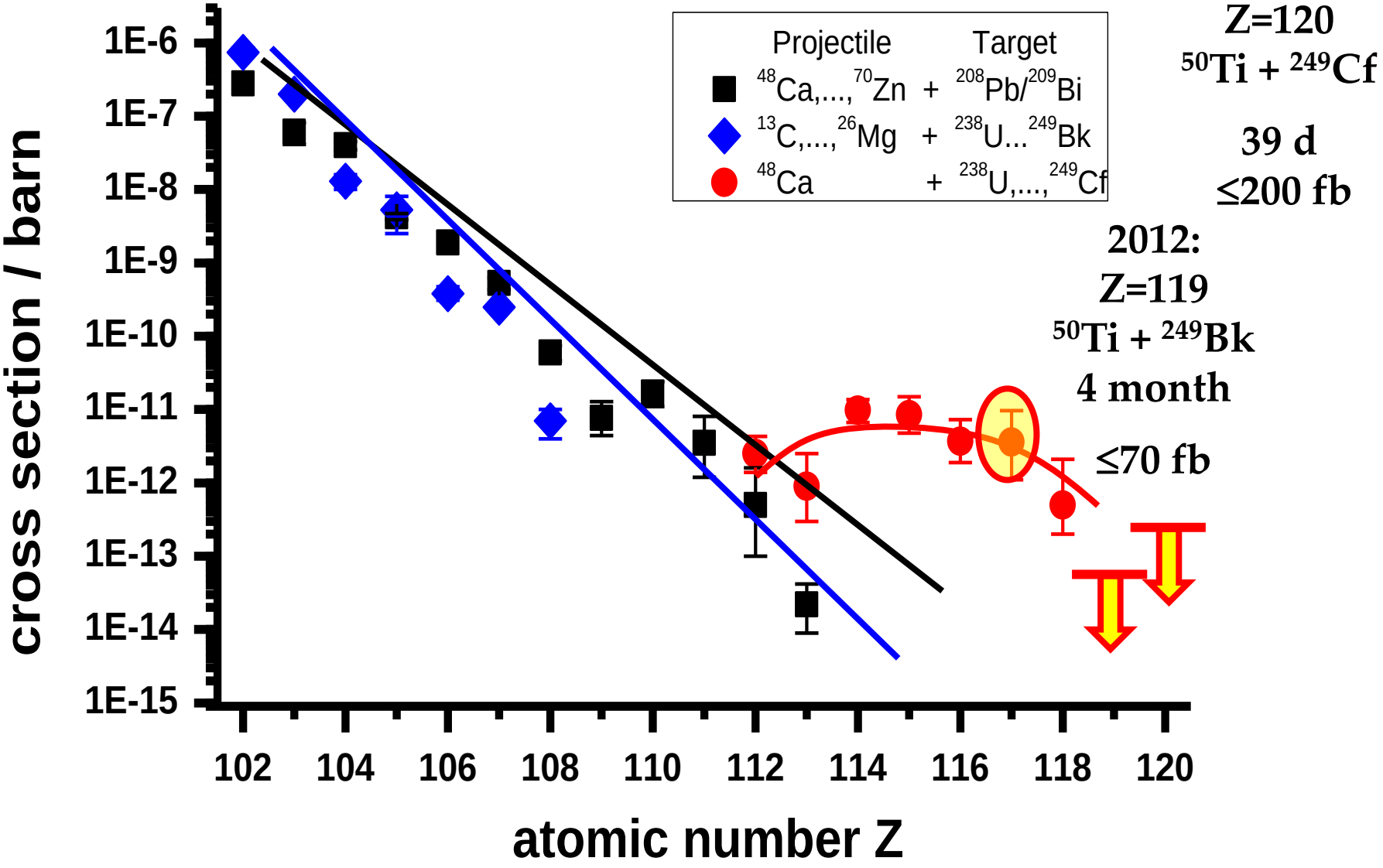
≈40 TB of data (analysis is ongoing)

Sensitivity ~70 fb for one event

Current status of data analysis yields
no evidence for detection of element 119

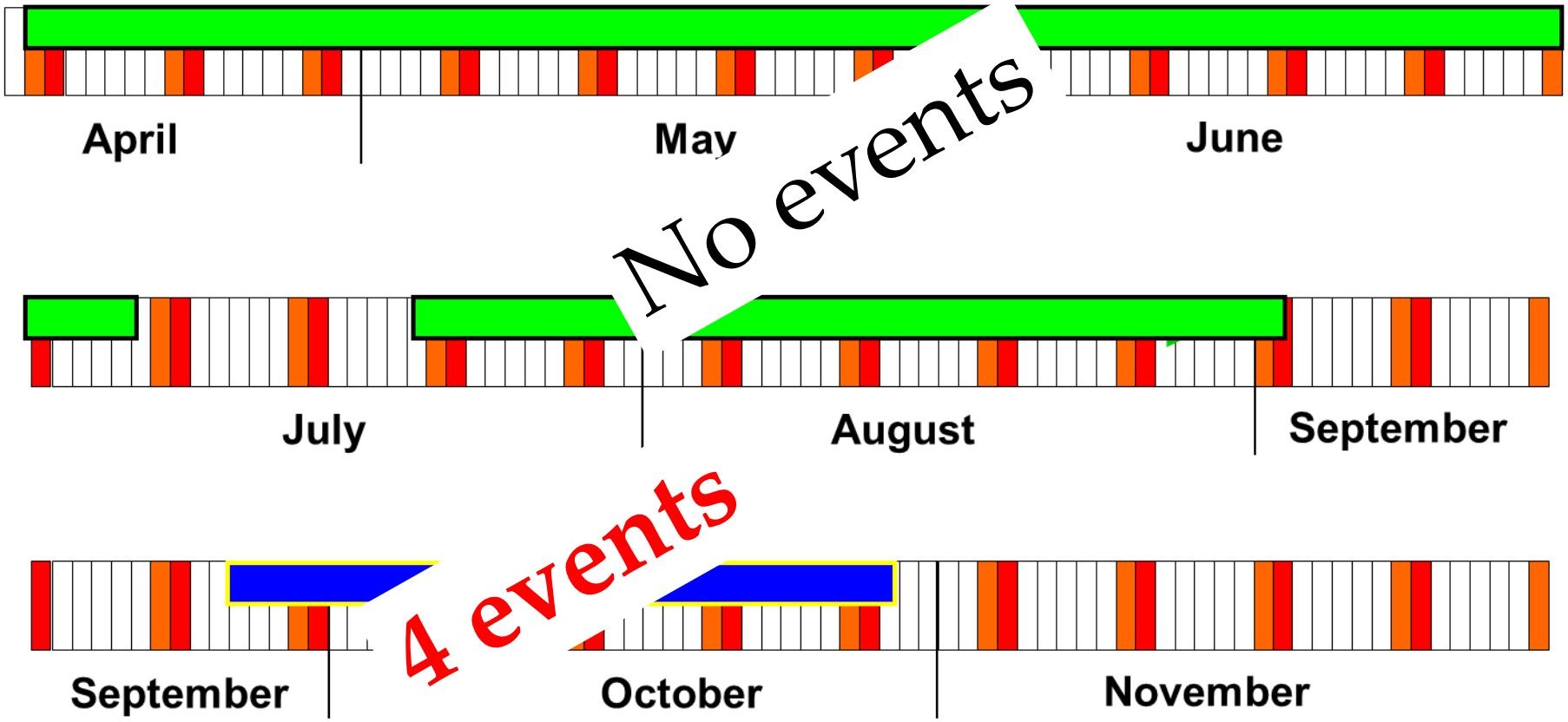
$^{50}Ti + ^{249}Bk \Rightarrow$ Element 119

Cross Sections



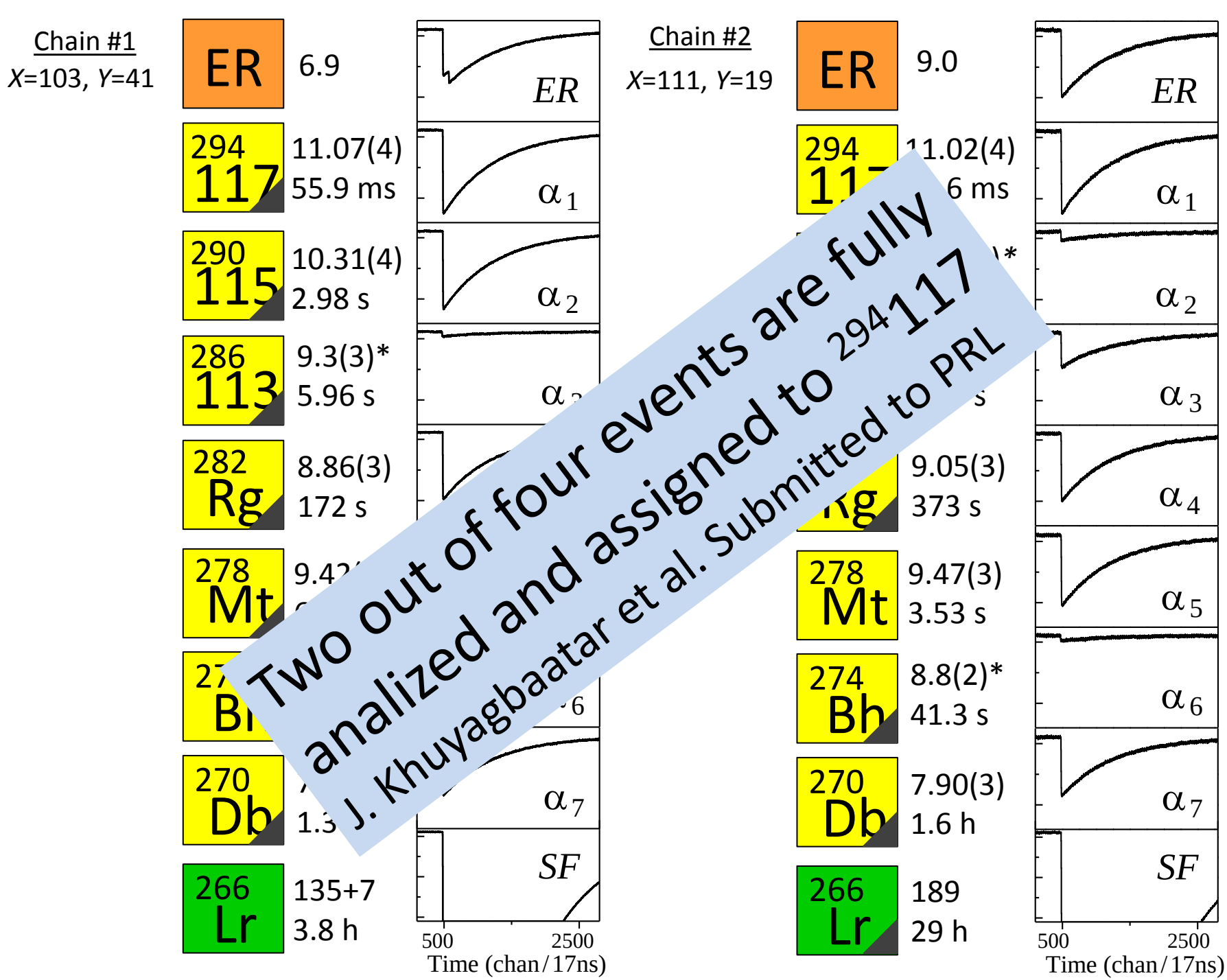
2012: Element 119 search / Element 117

^{50}Ti beam 750 nA$_p$ and ^{249}Bk targets with initial thickness ≈0.44 mg/cm^2.



^{48}Ca+^{249}Bk ⇒ Element 117

^{50}Ti+^{249}Bk ⇒ Element 119


Chain #1
X=103, Y=41
ER
6.9
294
117
11.07(4)
55.9 ms
290
115
10.31(4)
2.98 s
286
113
9.3(3)*
5.96 s
282
Rg
8.86(3)
172 s
278
Mt
270
Db
1.3
266
Lr
135+7
3.8 h
ER
α1
α2
SF
500
2500
Time (chan/17ns)
Chain #2
X=111, Y=19
ER
9.0
294
11.02(4)
6 ms
Rg
9.05(3)
373 s
278
Mt
9.47(3)
3.53 s
274
Bh
8.8(2)*
41.3 s
270
Db
7.90(3)
1.6 h
266
Lr
189
29 h
ER
α1
α2
α3
α4
α5
α6
α7
SF
500
2500
Time (chan/17ns)
Two out of four events are fully analized and assigned to 294117
J. Khuyagbaatar et al. Submitted to PRL

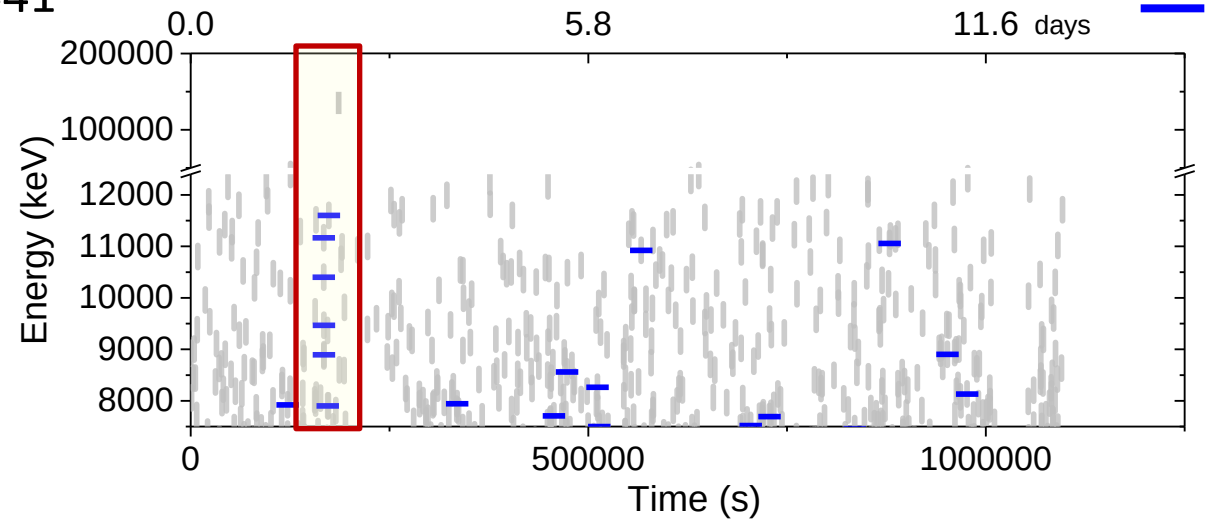
Chain 1

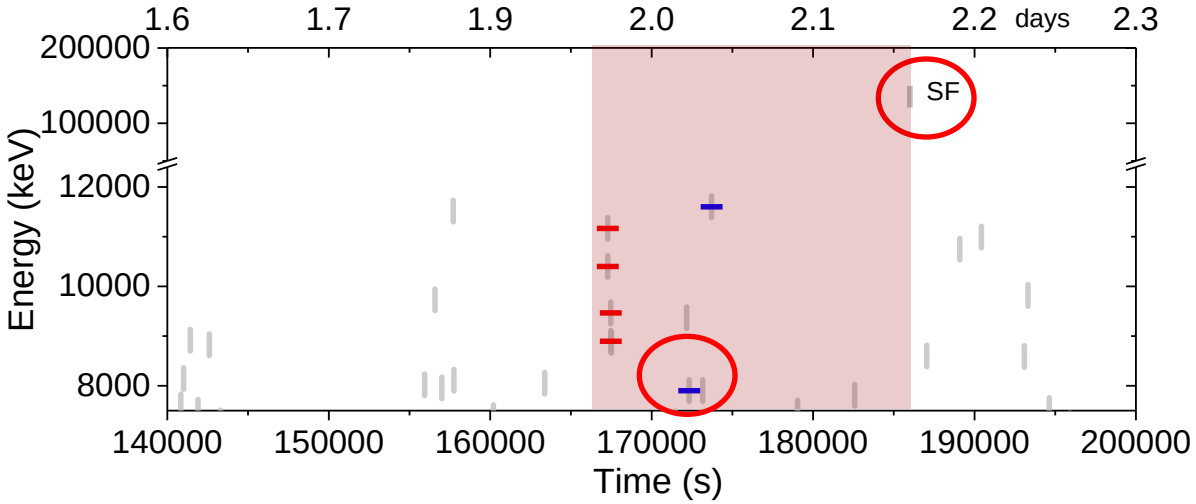
254 MeV-run

anti-MWPC

Beam off

ER	X=103, Y=41 6.9
^{294}117	11.07(4) 55.9 ms
^{290}115	10.31(4) 2.98 s
^{286}113	9.3(3)* 5.96 s
^{282}Rg	8.86(3) 172 s
^{278}Mt	9.42(3) 6.79 s
^{274}Bh	8.84(3) 45.1 s
^{270}Db	7.89(3) 1.3 h
^{266}Lr	135+7 3.8 h





One fission event only in this pixel

Random Probability for ER-α-α-α-α-α-α-SF

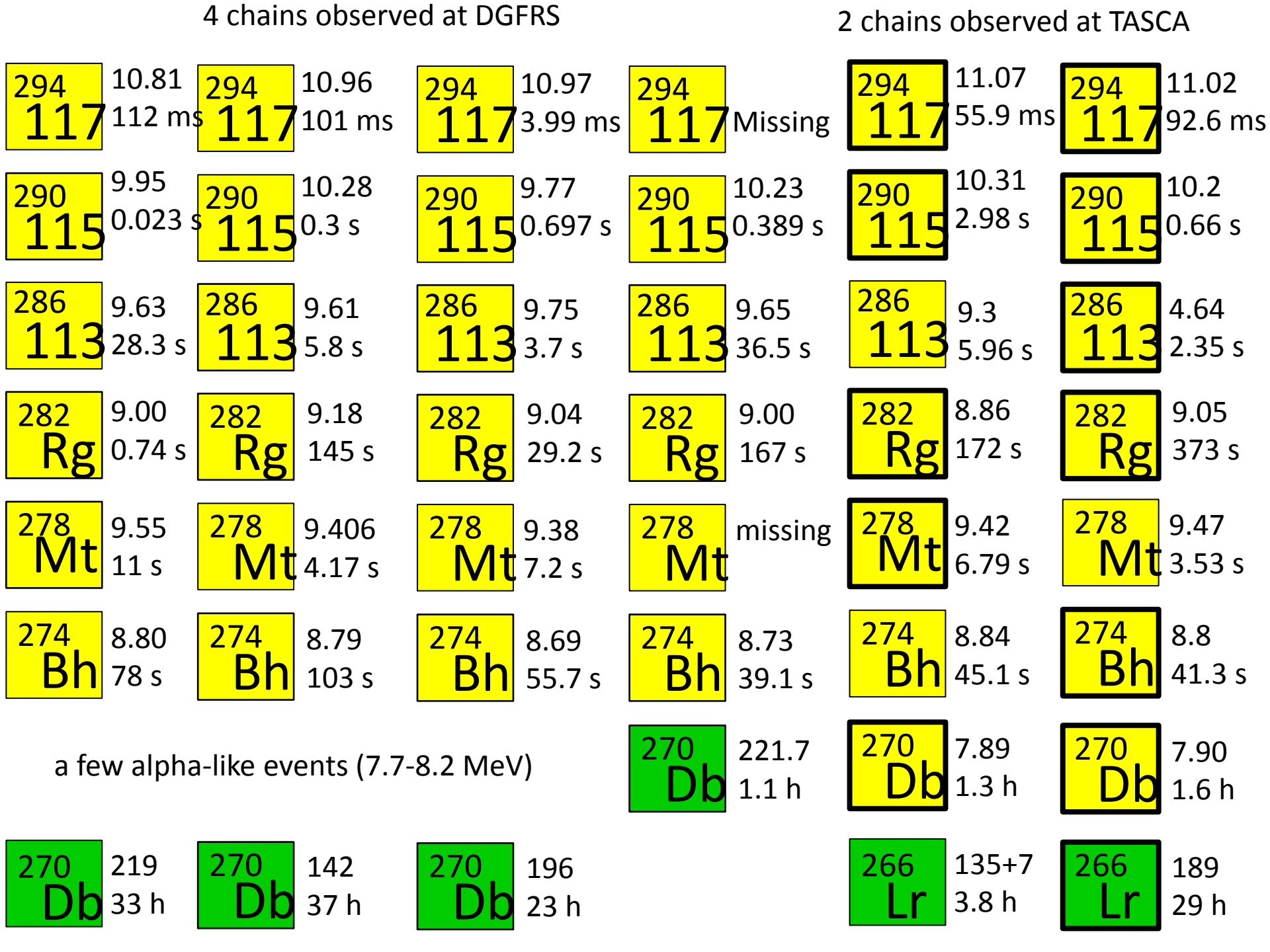
Eα=(7.8-12.0) MeV with same Δt's of chain $<3\cdot10^{-17}$

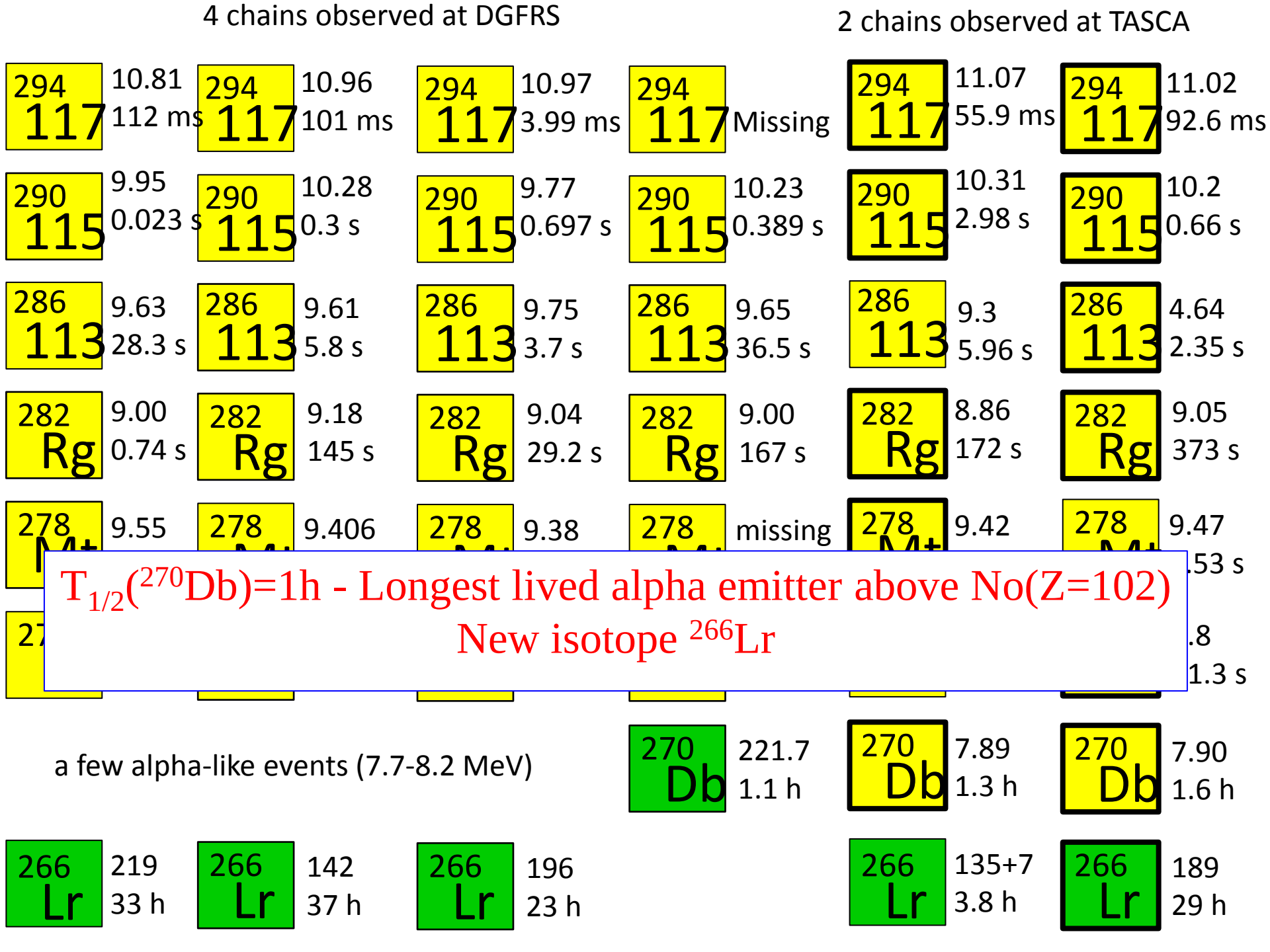
4 chains observed at DGFRS

$^{294}117$ 10.81 112 ms	$^{294}117$ 10.96 101 ms	$^{294}117$ 10.97 3.99 ms	$^{294}117$ Missing
$^{290}115$ 9.95 0.023 s	$^{290}115$ 10.28 0.3 s	$^{290}115$ 9.77 0.697 s	$^{290}115$ 10.23 0.389 s
$^{286}113$ 9.63 28.3 s	$^{286}113$ 9.61 5.8 s	$^{286}113$ 9.75 3.7 s	$^{286}113$ 9.65 36.5 s
^{282}Rg 9.00 0.74 s	^{282}Rg 9.18 145 s	^{282}Rg 9.04 29.2 s	^{282}Rg 9.00 167 s
^{278}Mt 9.55 11 s	^{278}Mt 9.406 4.17 s	^{278}Mt 9.38 7.2 s	^{278}Mt missing
^{274}Bh 8.80 78 s	^{274}Bh 8.79 103 s	^{274}Bh 8.69 55.7 s	^{274}Bh 8.73 39.1 s
^{270}Db 219 33 h	^{270}Db 142 37 h	^{270}Db 196 23 h	^{270}Db 221.7 1.1 h

TASCA

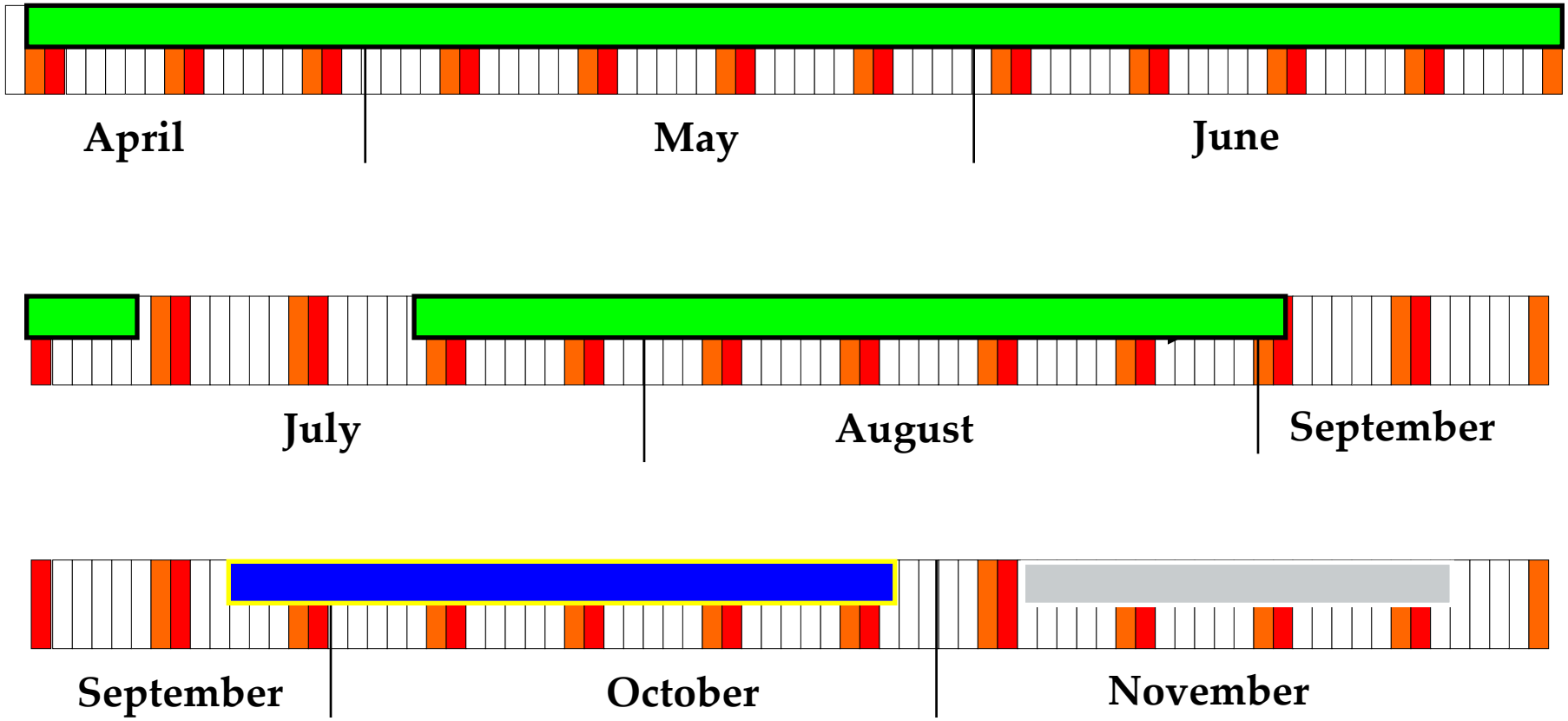
$^{294}117$ 11.07 55.9 ms	$^{294}117$ 11.02 92.6 ms
$^{290}115$ 10.31 2.98 s	$^{290}115$ 10.2 0.66 s
$^{286}113$ 9.3 5.96 s	$^{286}113$ 4.64 2.35 s
^{282}Rg 8.86 172 s	^{282}Rg 9.05 373 s
^{278}Mt 9.42 6.79 s	^{278}Mt 9.47 3.53 s
^{274}Bh 8.84 45.1 s	^{274}Bh 8.8 41.3 s
^{270}Db 7.89 1.3 h	^{270}Db 7.90 1.6 h
^{266}Lr 135+7 3.8 h	^{266}Lr 189 29 h


4 chains observed at DGFRS
2 chains observed at TASCA
294 117 10.81 112 ms
294 117 10.96 101 ms
294 117 10.97 3.99 ms
294 117 Missing
294 117 11.07 55.9 ms
294 117 11.02 92.6 ms
290 115 9.95 0.023 s
290 115 10.28 0.3 s
290 115 9.77 0.697 s
290 115 10.23 0.389 s
290 115 10.31 2.98 s
290 115 10.2 0.66 s
286 113 9.63 28.3 s
286 113 9.61 5.8 s
286 113 9.75 3.7 s
286 113 9.65 36.5 s
286 113 9.3 5.96 s
286 113 4.64 2.35 s
282 Rg 9.00 0.74 s
282 Rg 9.18 145 s
282 Rg 9.04 29.2 s
282 Rg 9.00 167 s
282 Rg 8.86 172 s
282 Rg 9.05 373 s
278 Mt 9.55 11 s
278 Mt 9.406 4.17 s
278 Mt 9.38 7.2 s
278 Mt missing
278 Mt 9.42 6.79 s
278 Mt 9.47 3.53 s
274 Bh 8.80 78 s
274 Bh 8.79 103 s
274 Bh 8.69 55.7 s
274 Bh 8.73 39.1 s
274 Bh 8.84 45.1 s
274 Bh 8.8 41.3 s
a few alpha-like events (7.7-8.2 MeV)
270 Db 221.7 1.1 h
270 Db 7.89 1.3 h
270 Db 7.90 1.6 h
270 Db 219 33 h
270 Db 142 37 h
270 Db 196 23 h
266 Lr 135+7 3.8 h
266 Lr 189 29 h


4 chains observed at DGFRS
2 chains observed at TASCA
294 117 10.81 112 ms
294 117 10.96 101 ms
294 117 10.97 3.99 ms
294 117 Missing
294 117 11.07 55.9 ms
294 117 11.02 92.6 ms
290 115 9.95 0.023 s
290 115 10.28 0.3 s
290 115 9.77 0.697 s
290 115 10.23 0.389 s
290 115 10.31 2.98 s
290 115 10.2 0.66 s
286 113 9.63 28.3 s
286 113 9.61 5.8 s
286 113 9.75 3.7 s
286 113 9.65 36.5 s
286 113 9.3 5.96 s
286 113 4.64 2.35 s
282 Rg 9.00 0.74 s
282 Rg 9.18 145 s
282 Rg 9.04 29.2 s
282 Rg 9.00 167 s
282 Rg 8.86 172 s
282 Rg 9.05 373 s
278 9.55
278 9.406
278 9.38
278 missing
278 9.42
278 9.47
T1/2(270Db)=1h - Longest lived alpha emitter above No(Z=102)
New isotope 266Lr
a few alpha-like events (7.7-8.2 MeV)
270 Db 221.7 1.1 h
270 Db 7.89 1.3 h
270 Db 7.90 1.6 h
266 Lr 219 33 h
266 Lr 142 37 h
266 Lr 196 23 h
266 Lr 135+7 3.8 h
266 Lr 189 29 h

2012: Element 115 Spectroscopy

^{50}Ti beam 750 nA$_p$ and ^{249}Bk targets with initial thickness ≈0.44 mg/cm^2.

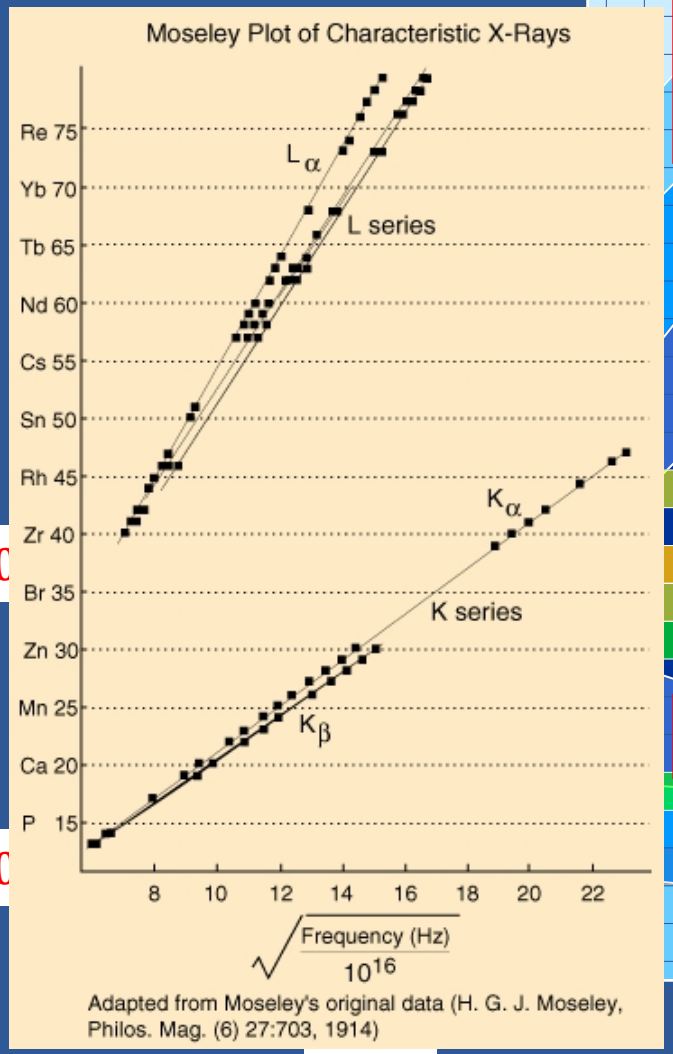


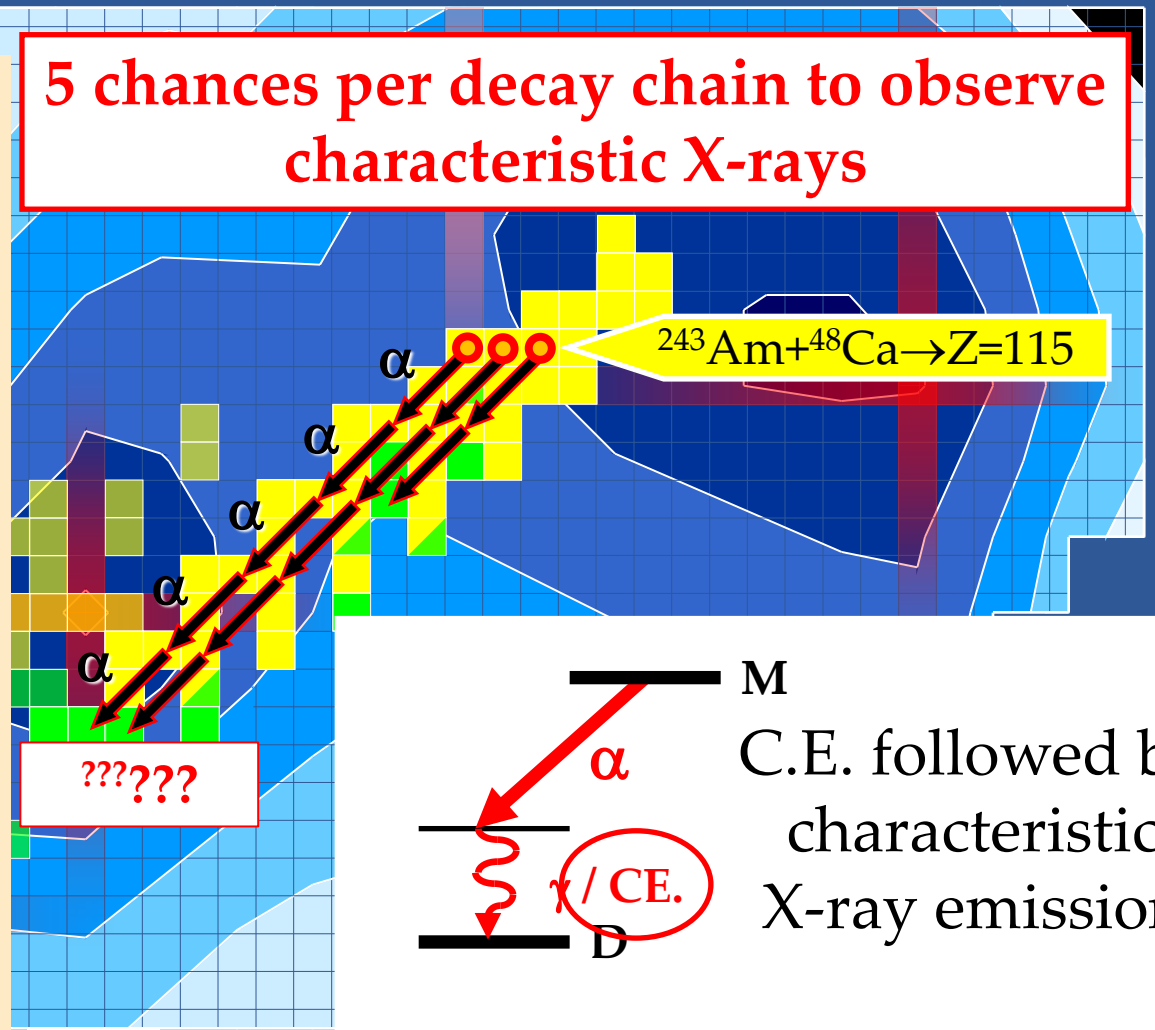
^{50}Ti+^{249}Bk⇒Element 119

^{48}Ca+^{249}Bk⇒Element 117

^{48}Ca+^{243}Am⇒Element 115

Fingerprinting the SHE
- Direct measurement of Z



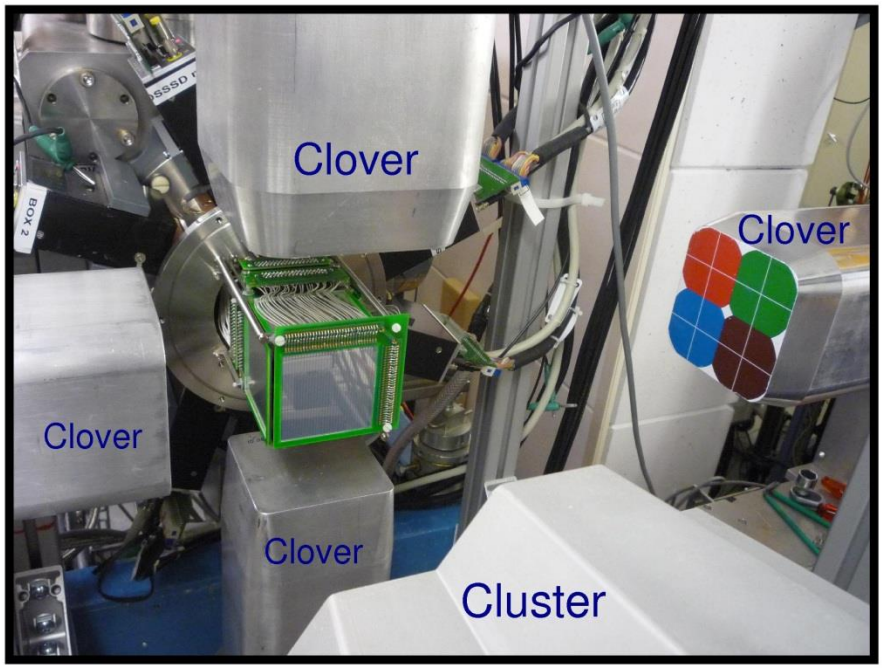


TASISpec

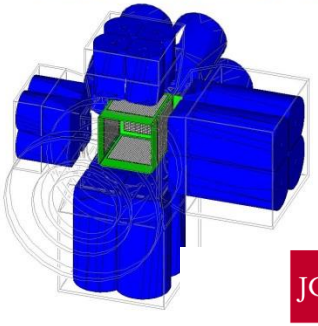
Highly efficient multi–coincidence spectroscopy set–up for TASCA's very compact focal plane image

1 Implantation DSSSD (1024 pixels)
4 box–DSSSDs (1024 pixels)
=> ~80% α–detection efficiency

4 Ge Clover (4*4 crystals)
1 Ge Cluster (7 crystals)
=> ~40% γ–detection eff. at 150 keV



L–L Andersson et al., NIM A 622, 164 (2010)
L.G. Sarmiento et al., NIM A 667, 26 (2011)



Virtually constructed with GEANT4 simulation package

LUND UNIVERSITY
UNIVERSITY OF LIVERPOOL
HELMHOLTZ ASSOCIATION
Helmholtz Institute Mainz
GSI
UNIVERSIDAD NACIONAL DE COLOMBIA
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
OAK RIDGE NATIONAL LABORATORY
Managed by UT-Battelle for the Department of Energy

^{243}Am target material

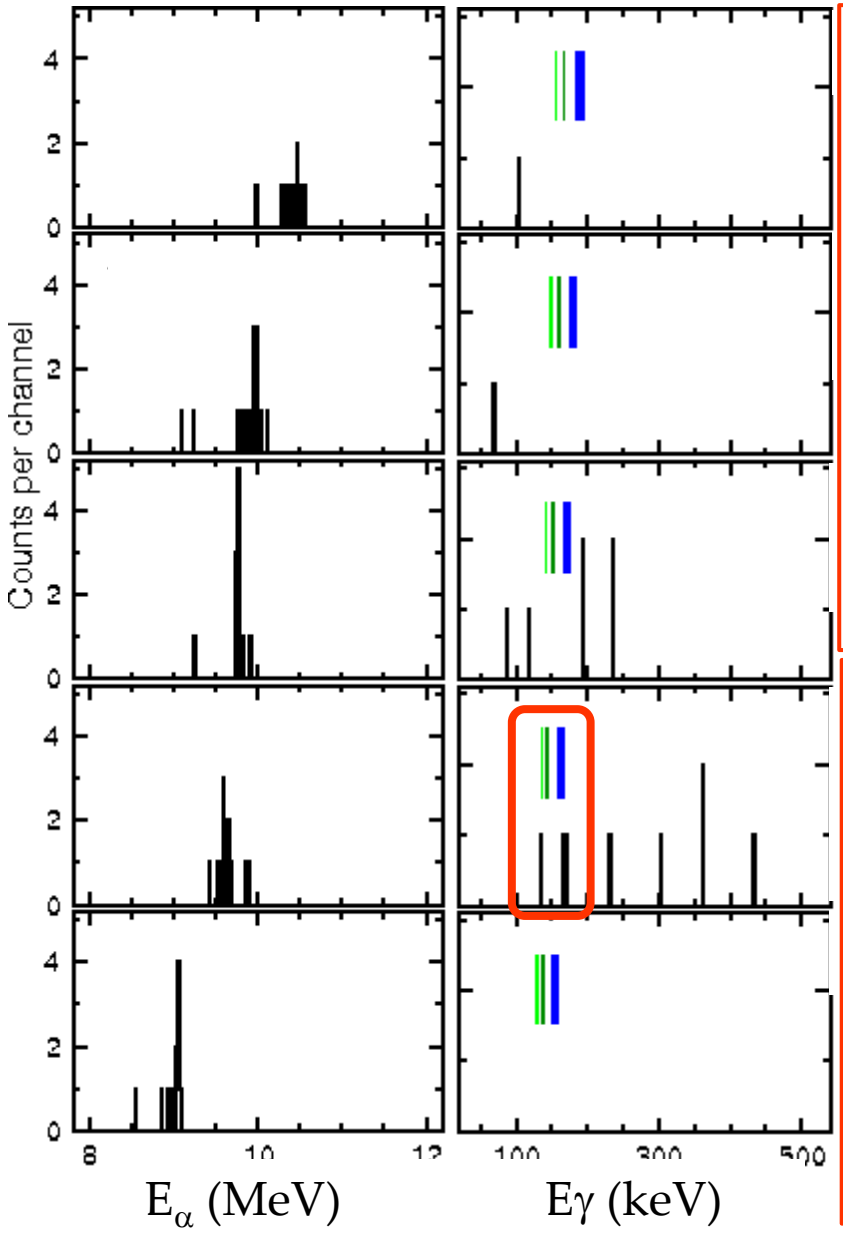
TASISpec: ^{243}Am(^{48}Ca,x*n*)$^{291-x}$115

Beam on target: 415h (82%) ~6·10^{18} ^{48}Ca 30x

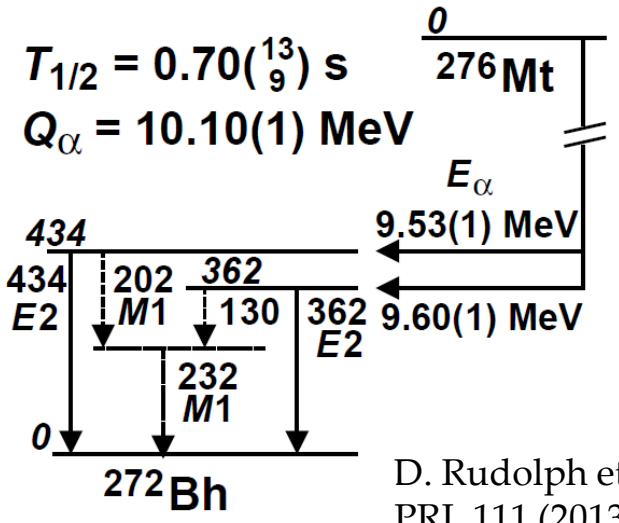
(tot. σ ~10 pb)

Only 64 fission events during beam-off periods within 3 weeks in 1024 DSSSD pixels

Spectra of the 22 "3n decay chains"



Hypothesis for level scheme



D. Rudolph et al.,
PRL 111 (2013) 112502

Mt → Bh 1x 136; 1x 167;
1x 172; 1x 232; 1x 303;
2x 362; 1x 434

Bh X-rays
$K_{\alpha 2}$: 136 keV
$K_{\beta 2}$: 167 keV

accurate to better than 0.5%

T.A. Carlson et al., NPA 135 (1969) 57

Difference between neighboring Z: 3-4 keV

Summary

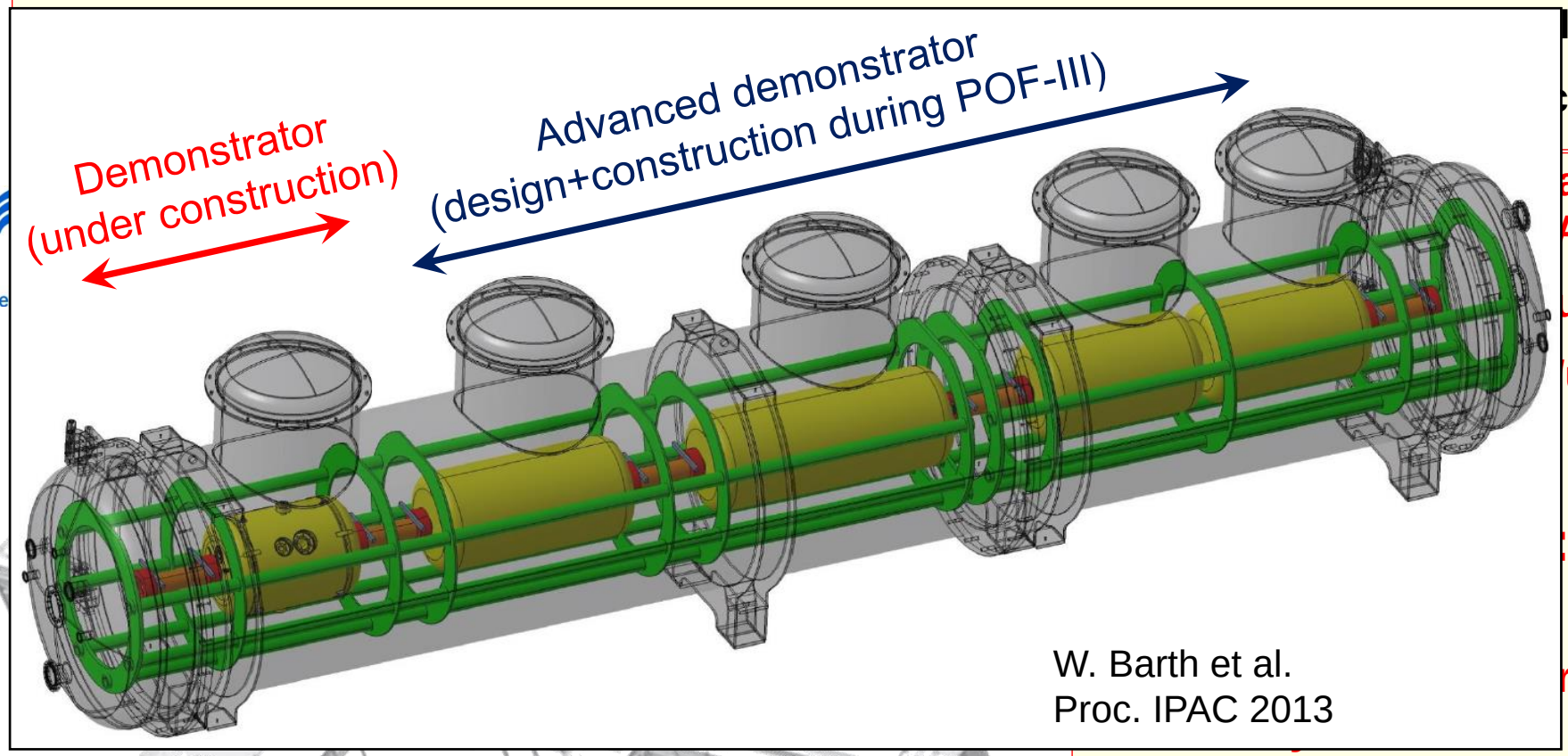
TASCA SHE program includes:

- ✓ **synthesis** of new elements and isotopes
- ✓ nuclear **reaction** studies
- ✓ nuclear **structure** studies
- ✓ **chemical properties** of SHE

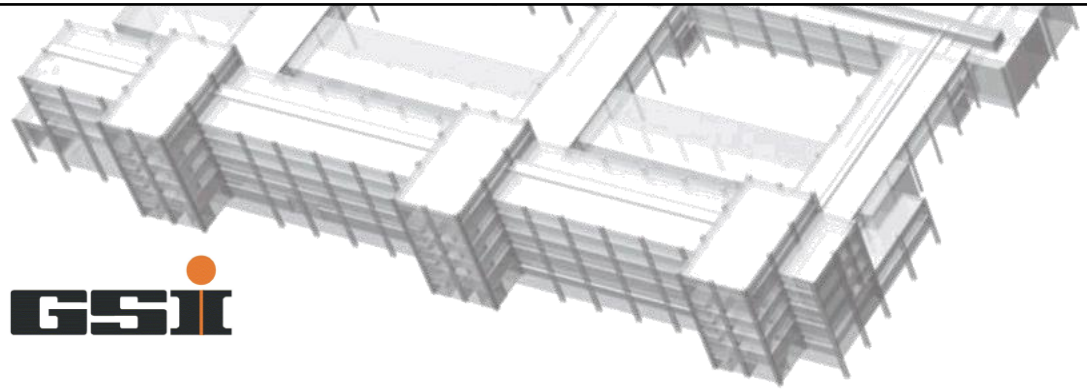
TASCA experiments 2011/12:

- Search for new elements with ^{50}Ti induced reactions
  - ✓ ^{249}Cf(^{50}Ti,xn)$^{299-x}$**120**: one-event TASCA limit is **<200 fb**
  - ✓ ^{249}Bk(^{50}Ti,xn)$^{299-x}$**119**: one-event TASCA limit is **<70 fb**
- Observation of **element 117 @ *TASCA***:
  - ✓ assures **proper operation** in 119/120 experiments
  - ✓ **confirms DGFRS** chains
- First **spectroscopy** with decay chains starting from E115

Outlook: A Dedicated SHE LINAC



W. Barth et al.
Proc. IPAC 2013



Commissioning: 2015

2) Contruct multicell string during POF 3 (2015-2019) Useful for SHE research, synergies for FAIR!

3) Contruct full linac

Chemical studies

On the way to ALBEGA

A detection system for ALpha/BEta/GAmma spectroscopy of chemically separated samples

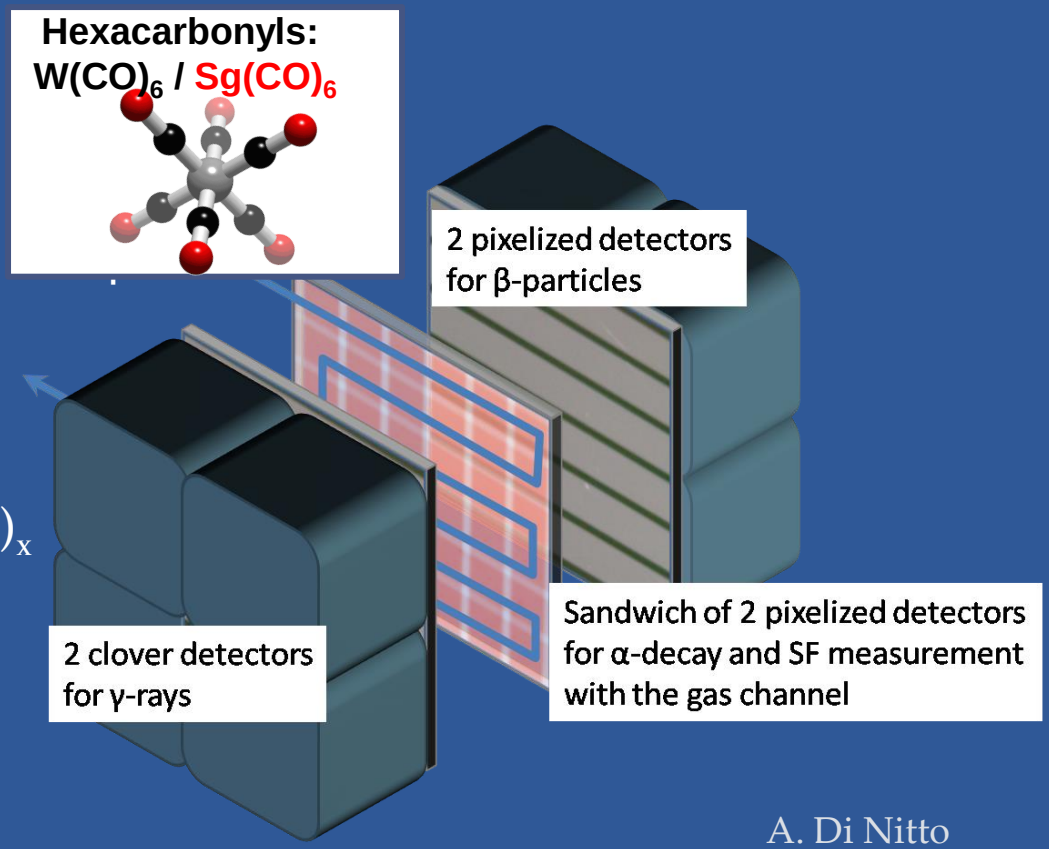
Si array ~ 70 x 70 mm² active area, consiting of:

- „sandwich“ detector with 2 x 32 single diodes (α/SF)
- thick Si strip detectors (e^-)

Array cooled to ~ -100 °C

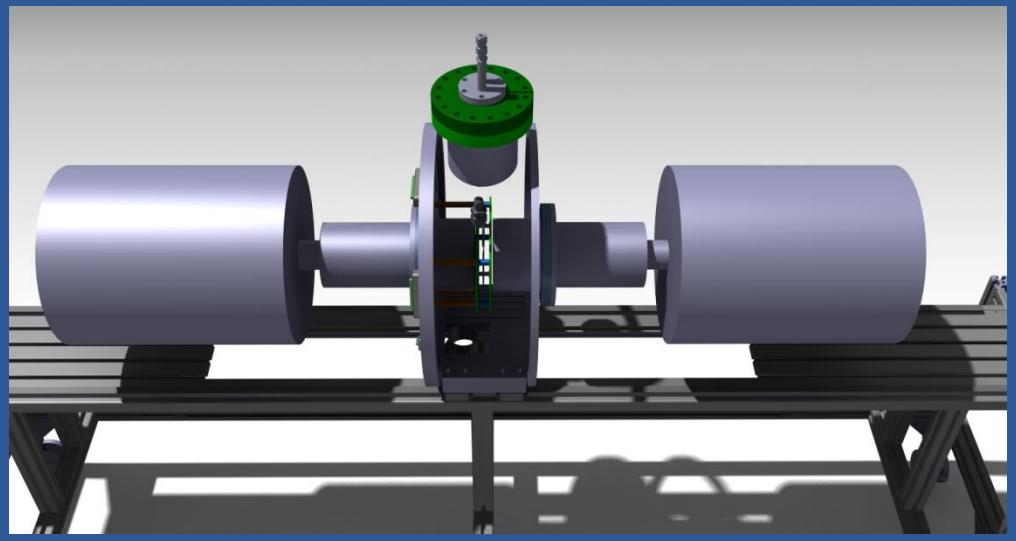
⇒ quantitative adsorption of $M(CO)_x$

- 2 Clover Ge detectors (γ)

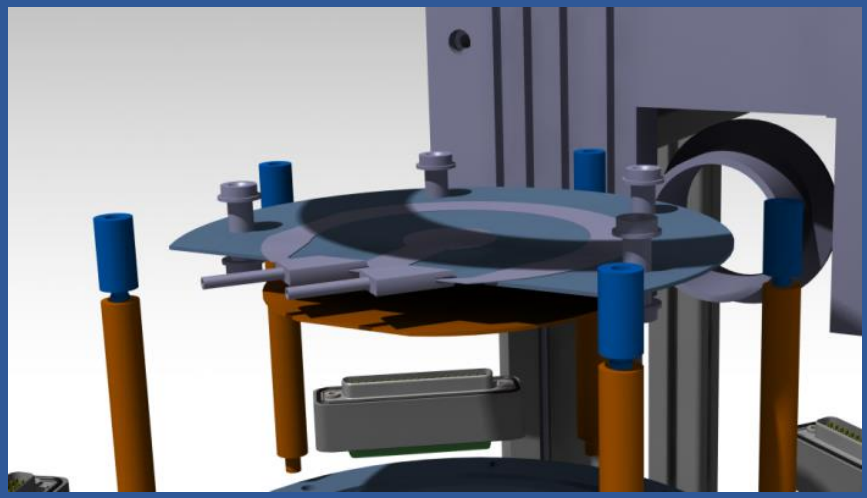


A. Di Nitto
A. Yakushev

ALBEGA

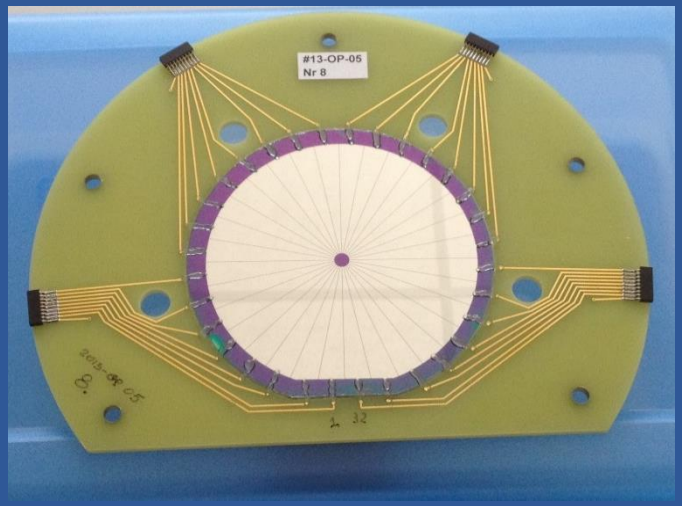


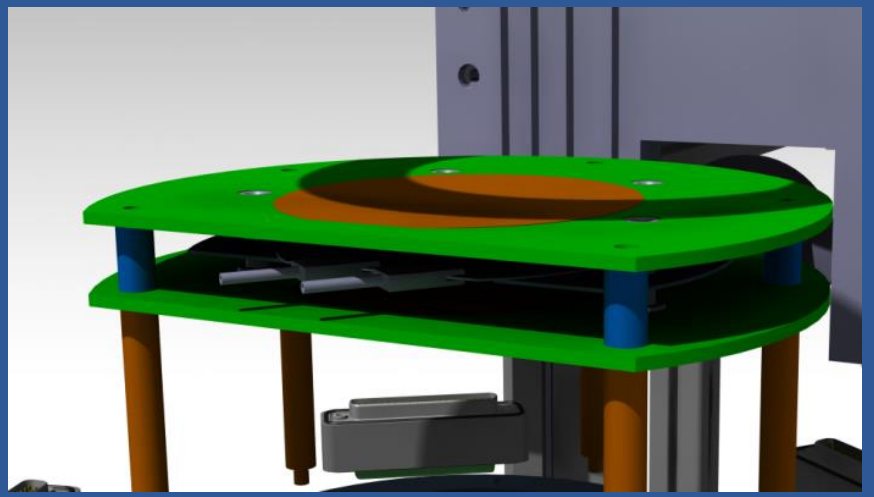
2 BEGe detectors, ø 90 mm



Alpha detector sandwich

2 Beta detectors, 1mm Si





Beamtime: April 4-8, 2014

Thanks to all collaborators and for your attention!